



**ENERGY, MINES AND
RESOURCES CANADA**

**CANADA CENTRE FOR MINERAL AND
ENERGY TECHNOLOGY**

NATIONAL URANIUM TAILINGS PROGRAM

FINAL REPORT

ON

RADIUM REMOVAL FROM

CANADIAN URANIUM MINING EFFLUENTS

BY A RADIUM-SELECTIVE ION EXCHANGE COMPLEXER

JULY, 1984

MELIS CONSULTING ENGINEERS LTD.

MELIS CONSULTING ENGINEERS LTD.

Metallurgical Engineering Services

155 A.E. Adams Crescent
Saskatoon, Saskatchewan, Canada
S7K 5M6
(306) 242-1021

September 14, 1984

Energy, Mines and Resources
CANMET
National Uranium Tailings Program
555 Booth Street
OTTAWA, Ontario
K1R 7L1

ATTENTION: MR. D.G. FEASBY

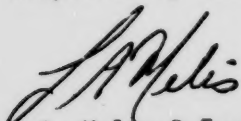
Dear Mr. Feasby:

We are pleased to submit twenty (20) copies of the final report entitled "Radium Removal from Canadian Uranium Mining Effluents by a Radium-Selective Ion Exchange Complexer" which presents the results of laboratory testwork carried out under contract to the Department of Supply and Services.

We trust the information included in this report meets your requirements and we remain available to answer questions or discuss any aspects of the report at your convenience.

Melis Consulting Engineers Ltd. wishes to express its sincere appreciation for the opportunity to be of service to the National Uranium Tailings Program and we look forward to providing further assistance in the future.

Respectfully submitted,



L.A. Melis, P.Eng.
Principal

Melis Consulting Engineers Ltd.
APES Cert. of Authorization No. 418
LAM:dm
att.

CONTRACT REPORT No. OSQ 83-00231
RADIUM REMOVAL FROM

CANADIAN URANIUM MINING EFFLUENTS

BY A RADIUM-SELECTIVE

ION EXCHANGE COMPLEXER

prepared for

DEPARTMENT OF ENERGY, MINES AND RESOURCES
CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY
NATIONAL URANIUM TAILINGS PROGRAM

by

MELIS CONSULTING ENGINEERS LTD.

NOV 22 1984

148 pp

MICROMEDIA

July, 1984

Saskatoon, Canada

RADIUM REMOVAL FROM
CANADIAN URANIUM MINING EFFLUENTS
BY A RADIUM-SELECTIVE
ION EXCHANGE COMPLEXER

TABLE OF CONTENTS

	<u>Page No.</u>
<u>EXECUTIVE SUMMARY</u>	
1.0 <u>INTRODUCTION</u>	1
2.0 <u>SUMMARY OF RESULTS</u>	3
3.0 <u>LABORATORY TESTWORK</u>	17
3.1 Sample Description	17
3.1.1 Radium-Selective Complexer	17
3.1.2 Water Samples	17
3.2 Test Methodology	22
3.3 Test Results	31
3.3.1 Water Analyses	31
3.3.2 Water and Radium Balances	43
3.3.3 Resin Analyses	52
3.3.4 Radiation Measurements	55
3.3.5 Resin Loading Capacity	61
4.0 <u>RADIATION EXPOSURE POTENTIAL</u>	68
5.0 <u>DECONTAMINATION</u>	70
6.0 <u>DISPOSAL</u>	71

Radium Removal from
Canadian Uranium Mining Effluents
by a Radium-Selective
Ion Exchange Complexer
Table of Contents (Cont'd)

	<u>Page No.</u>
7.0 <u>COST ESTIMATE</u>	73
8.0 <u>CONCLUSIONS</u>	80
9.0 <u>RECOMMENDATIONS</u>	84
10.0 <u>REFERENCES</u>	87
PLATES	
APPENDICES	

LIST OF TABLES

<u>Table No.</u>	<u>Description</u>	<u>Page No.</u>
E-1	Resin Analysis Summary	(iii)
E-2	Panel Analysis Summary	(iv)
E-3	Key Lake Analysis Summary	(v)
E-4	Column No. 1 Radium Removal Efficiencies	(vii)
E-5	Resin Radium-Loading Capacity	(ix)
2-1	Test Operating Parameters	4
2-2	Resin Physical Characteristics	5
2-3	Feed and Discharge Analyses	9
2-4	Resin Analyses	10
2-5	Column No. 1 Efficiencies	12
2-6	Resin Analysis Summary	14
2-7	Resin Radium-Loading Capacity	16
3-1	Physical Properties of Dow Radium-Selective Complexer	18
3-2	Resin Complexer Analysis	19
3-3	Contaminated Water Analyses	21
3-4	pH Measurements on Feed Samples	23
3-5	Operating Parameters for Panel and Key Lake Column No. 1	26
3-6	Panel Column No. 1 Increased Flowrate Data	28
3-7	Panel Test Dissolved Radium-226 Analyses	32
3-8	Key Lake Test Dissolved Radium-226 Analyses	36
3-9	Effect of Specific Flowrate on Radium Removal	41
3-10	Column No. 3 Final Discharge Analysis	42
3-11	Analyses of Precipitates in Key Lake Column No. 1	44
3-12	Panel Test - Summary of Column No. 1 Results	48
3-13	Key Lake Test - Summary of Column No. 1 Results	49
3-14	Column No. 2 and No. 3 Results	53
3-15	Resin Radium-226 Analyses	54
3-16	Loaded Resin Analyses	56

LIST OF TABLES

(Cont'd)

<u>Table No.</u>	<u>Description</u>	<u>Page No.</u>
3-17	Panel Column No. 1 Gamma Radiation Surveys	58
3-18	Key Lake Column No. 1 Gamma Radiation Surveys	59
3-19	Radon Measurements	62
3-20	Key Lake Column No. 1 Radium Loading and Radiation Measurements	63

LIST OF FIGURES

<u>Figure No.</u>	<u>Description</u>	<u>Page No.</u>
2-1	Column No. 1 Discharge Analysis vs Bed Volumes of Water Treated	6
2-2	Column No. 1 Discharge Radium Analyses as Percent of Feed	8
2-3	Batch Radium Removal Efficiency in No. 1 Column vs Bed Volumes of Water Treated	13
3-1	Test Apparatus	24
3-2	Bed Expansion vs Specific Flowrate	29
3-3	Fluidization Characteristics of Dowex XFS 43230.00 Resin	30
3-4	Panel Column No. 1 Discharge Analyses vs Bed Volumes of Water Treated	33
3-5	Panel Columns No. 2 and No. 3 Discharge Results	34
3-6	Key Lake Column No. 1 Discharge Analysis vs Bed Volumes of Water Treated	37
3-7	Key Lake Columns No. 2 and No. 3 Discharge Results	38
3-8	Column No. 1 Discharge Radium Analysis as Percent of Feed	39
3-9	Panel Water and Radium Balance	46
3-10	Key Lake Water and Radium Balance	47
3-11	Batch Radium Removal Efficiency in No. 1 Column vs Bed Volumes of Water Treated	50
3-12	Cumulative Radium Removal Efficiency vs Bed Volumes of Water Treated	51
3-13	Key Lake Column No. 1 Radiation Surveys	60
3-14	Key Lake Column No. 1 Resin Radium Loading and Radiation Measurements on Column Surface	64
3-15	Key Lake Column No. 1 Net Radiation Values at Test Completion	66

LIST OF PLATES

<u>Plate No.</u>	<u>Description</u>
1	Test equipment showing columns
2	Test equipment showing columns and feed tanks
3	Precipitate in Key Lake Column No. 1
4	Precipitate in Panel Column No. 1

APPENDICES

Appendix A. Dow Radium Complexer XFS 43230.00 - Material Safety Data Sheet

Appendix B. Radium-226 Analytical Method

Appendix C. Water and Radium Balances - Panel Individual Batches

Appendix D. Water and Radium Balances - Key Lake Individual Batches

Appendix E. Radiation Exposure Potential Estimates

ACKNOWLEDGEMENTS

The assistance provided by Rio Algom Ltd. and Key Lake Mining Corporation in obtaining the bulk samples of water used in the test program was greatly appreciated and is hereby acknowledged. The cooperation of Saskatchewan Research Council personnel during the course of the program, and in particular Mr. R. McKnight who was directly responsible for carrying out the laboratory tests, is also appreciated. Input from the National Uranium Tailings Program office ensured the successful completion of the project.

RADIUM REMOVAL FROM
CANADIAN URANIUM MINING EFFLUENTS
BY A RADIUM-SELECTIVE
ION EXCHANGE COMPLEXER

EXECUTIVE SUMMARY

Introduction

A laboratory test program was initiated by the Department of Energy, Mines and Resources as part of the National Uranium Tailings Program to investigate the applicability of a radium-selective ion exchange complexer for removing radium from Canadian uranium mining effluents. The test program was carried out by Melis Consulting Engineers Ltd. under contract to the Department of Supply and Services using the Saskatchewan Research Council facilities located in Saskatoon, Saskatchewan.

The results of this work showed the ion exchange complexer to be efficient in removing radium from contaminated water of uranium mining operations with the ultimate loading capacity of the resin on one type of water treated being determined as approximately $1,600 \text{ Bq/cm}^3$ of new resin. Although this resin has potential application for treatment of effluent streams in uranium operations it has been identified that the resin efficiency and capacity is directly related to the chemistry of the water being treated and that further work would be required in order to establish reliable design data for full-scale operations.

Test Program

The radium-selective complexer, Dowex XFS 43230.00 supplied by Dow Chemical Canada Inc. of Sarnia, Ontario, was evaluated on two different types of contaminated water; tailings decant water from Rio Algom Ltd.'s Panel uranium mine in Elliot Lake, Ontario and minewater, collected as grinding circuit process water, from the Key Lake uranium mine in northern Saskatchewan. Initially it was expected that seepage and runoff from the Key Lake tailings area could be used for the testwork but this proved not to be

possible due to bulk sampling difficulties.

A total of 4,832 L of Panel water was treated through three 1.27 cm diameter resin columns in series under upflow conditions at a specific flowrate of $16.6 \text{ m}^3/\text{h}/\text{m}^2$. A total of 4,564 L of Key Lake water was treated in a set of three 1.91 cm diameter resin columns in series at a specific flowrate of $11.8 \text{ m}^3/\text{h}/\text{m}^2$. Mass and radium balances as well as radium removal efficiencies were determined by recording the weights of feed and discharge solutions and analysing weekly samples for dissolved Ra-226. Gamma radiation measurements were taken at regular intervals during the testwork to monitor the radiation exposure potential of the radium-loaded resin.

After completing the treatment of the Panel and Key Lake bulk samples the resin columns in each set were drained of water and the resin was removed for analysis. The ultimate loading capacity of the resin was estimated by analysis and by extrapolation of the data obtained from the test program.

Radiation exposure potential, decontamination of resin columns, disposal of loaded resin, and cost estimates were briefly evaluated in conjunction with the laboratory test program.

Test Results

The chemical and physical characteristics of the resin used in the testwork are summarized in Table E-1. A 20-25% loss in volume was observed within twenty-four hours of placing the resin in service in both the Panel and Key Lake tests. This loss in volume, which is due to an exchange of calcium ions from the water being treated for sodium ions in the resin, accounts for the increase in density of loaded resin relative to new resin. It was determined in the Panel test that an increase in flowrate to $33 \text{ m}^3/\text{h}/\text{m}^2$ was required for a 100% bed expansion. Radium analyses of discharge solutions showed that radium removal efficiencies were not affected by operating at this specific flowrate as compared to a flowrate of $16.6 \text{ m}^3/\text{h}/\text{m}^2$.

Analyses of feed and Column No. 3 discharge solutions as well as loaded resin are summarized in Tables E-2 and E-3 for the Panel and Key Lake tests

TABLE E-1RESIN ANALYSIS SUMMARY (as received)

<u>Element</u>	<u>Analysis ($\mu\text{g/g}$)</u>
Ra-226 (Bq/g)	< 1
U	-
Al	28
Ba	1,800
Ca	300
Mg	20
Na	60,000
Co	5
Cr	300
Cu	6
Fe	590
Mn	26
Mo	<4
Ni	200
Zn	40
As	<1

PHYSICAL

Bulk density of wet settled resin (g/cm^3)	0.84
Moisture of drained settled resin (% H_2O)	72
Loss in volume after placing in service (%)	25
g dry resin/cm^3 of wet settled resin - as received	0.23
- loaded	0.30
Specific flowrate for 100% bed expansion ($\text{m}^3/\text{h/m}^2$)	33
Mesh size	20 x 50
Physical appearance	uniform beads

TABLE E-2

PANEL ANALYSIS SUMMARY

<u>Element</u>	<u>Feed (mg/L)(1)</u>	<u>Discharge (mg/L)(1)</u>	<u>Loaded Resin (µg/g)(2)</u>
Ra-226 (total)	6.7 Bq/L	0.20 Bq/L	1,200 Bq/g
Ra-226 (diss.)	6.7 Bq/L	0.20 Bq/L	-
U	0.19	0.21	8
Al	0.13	1.3	560
Ba	0.046	0.087	2,700
Ca	400	335	55,700
Mg	13	19	1,600
Na	58	91	640
K	85	149	-
Co	0.013	0.015	5
Cr	0.010	0.002	270
Cu	0.084	0.077	36
Fe	0.50	0.076	1,400
Mn	0.28	0.32	42
Mo	<0.005	<0.005	<4
Ni	0.056	0.093	100
Zn	0.11	0.79(3)	62
As	0.003	-	-
pH	4.8		

- NOTES: 1. The discharge sample analysed was the discharge from Column No. 3 at test completion after treatment of 69,350 bed volumes of water. The feed sample is representative of the first batch of water treated.
2. The analysis of loaded resin is for Column No. 1 resin. The results given are on a dry weight basis.
3. High zinc value is likely due to slight dissolution of brass fittings used in test equipment.

TABLE E-3

KEY LAKE ANALYSIS SUMMARY

<u>Element</u>	<u>Feed (mg/L)(1)</u>	<u>Discharge (mg/L)(1)</u>	<u>Loaded Resin (ug/g)(2)</u>
Ra-226 (total)	60 Bq/L	0.25 Bq/L	4,064 Bq/g
Ra-226 (diss.)	60 Bq/L	0.19 Bq/L	-
U	2.3	1.1	359
Al	0.076	0.059	19
Ba	0.038	0.12	2,100
Ca	38	61	33,500
Mg	36	35	13,800
Na	11	12	260
K	20	20	-
Co	0.024	0.022	14
Cr	0.008	0.005	410
Cu	0.017	0.037	23
Fe	0.35	0.23	800
Mn	0.18	0.19	95
Mo	0.43	0.39	92
Ni	13	11	5,800
Zn	0.086	0.17(3)	59
As	1.0	0.29	360
pH	5.1		

- NOTES: 1. The discharge sample analysed was the discharge from Column No. 3 at test completion after treatment of 21,700 bed volumes of water. The feed sample is representative of the first batch of water treated.
2. The analysis of loaded resin is representative of the total resin in Column No. 1.
The results given are on a dry weight basis.
3. High zinc value likely due to slight dissolution of brass fittings used in test equipment.

respectively. The discharge and loaded resin analyses given in each table are after treatment of 69,350 bed volumes of Panel tailings decant water assaying 6.7 Bq/L Ra-226 (diss.) and after treatment of 21,700 bed volumes of Key Lake grinding circuit process water assaying 60 Bq/L Ra-226 (diss.).

These results show that the Dowex XFS 43230.00 radium-selective complexer is efficient in removing radium from the two types of contaminated water treated but was not efficient in removing any other contaminants. The decrease in arsenic for the Key Lake water was attributed to the formation of a small amount of precipitate above the resin bed during operation of the Key Lake column which led to removal of some of the arsenic in the feed. The apparent increase in zinc concentration for both the Panel and Key Lake discharge samples was likely due to the use of brass fittings in the test equipment which resulted in a slight dissolution of zinc into the discharge solution.

An assessment of the loaded resin analysis for both tests against the new resin analysis given in Table E-1 shows that the resin has minor affinity for iron, nickel, molybdenum and arsenic but this is insignificant in terms of water treatment requirements. The exchange of calcium ions and magnesium ions for sodium ions is evident from the results. The significantly higher level of calcium for the Panel resin is a reflection of the high concentration of calcium ions in the Panel water. The lower radium loading on the Panel resin is due to the lower radium content in the Panel tailings decant water relative to the Key Lake grinding circuit process water.

Radium removal efficiencies for the lead column in the Panel and Key Lake tests are summarized in Table E-4. In both sets there was a gradual decrease in radium removal efficiency which was directly related to the number of bed volumes of water treated as well as to the chemistry of the water being treated.

The average radium removal efficiency of the second column of each set during the total operating period was 79% and 86% for Panel and Key Lake

TABLE E-4

COLUMN No. 1 RADIUM REMOVAL EFFICIENCIES

<u>Batch No.</u>	<u>Panel</u>		<u>Key Lake</u>	
	<u>Bed Volumes</u> <u>(Cumulative)</u>	<u>% Ra Removal</u> <u>(Batch)</u>	<u>Bed Volumes</u> <u>(Cumulative)</u>	<u>% Ra Removal</u> <u>(Batch)</u>
1	13,400	99.0	4,030	99.1
2	28,336	96.3	8,381	99.1
3	42,533	92.5	13,232	98.4
4	55,236	88.1	17,585	96.5
5	69,350	81.3	21,687	95.4

respectively. Radium removal by Column No. 3 was negligible relative to the first two columns. Radium levels in the discharge of the last column (Column No. 3) remained below the regulatory requirement of 0.37 Bq/L Ra-226 (total) for the total operating period of each set.

The discharge analyses towards the end of the test program seemed to indicate a decrease in radium removal efficiency for Column No. 2 and No. 3 in each set. Although there is insufficient data to draw any firm conclusions it appears that resin poisoning may have occurred during the operating period which could have affected the efficiency of the resin in the last two columns.

The ultimate radium-loading capacity of the resin was estimated for the Key Lake system using the data generated in the test program since it was not possible to achieve full saturation of the resin with the bulk sample of water that was available for test purposes. These estimates are summarized in Table E-5 along with analysis of the resin in the bottom of the lead column for the Key Lake test. The ultimate loading capacity of the resin, when treating the Key Lake water, was estimated as 2,100 to 2,265 Bq/cm³ of wet settled loaded resin which is equivalent to 1,580 to 1,700 Bq/cm³ of new wet settled resin. The lower equivalent value for new resin is due to the volume loss that occurs when the resin is placed into service. The results of the Panel test indicates that lower resin loadings should be expected when treating effluents containing high levels of calcium (0.4 g/L Ca).

In actual practice the loading capacity of the resin in the first column of a three-column operation in series would be dictated by the level of radium in the discharge of the last column since levels of less than 0.37 Bq/L Ra-226 (total) would need to be maintained in the last column discharge in order to meet regulatory guidelines. In addition, the service life of the resin in the first column, assuming the resin would need to be disposed of once it was loaded, would be dictated by the level of radium in the water being treated since the resin has a finite capacity. From the results of the test program it appears that in a three-column operation unacceptable levels of radium would be reached in the last column discharge before the resin in the lead column reached its full capacity.

TABLE E-5

RESIN RADIUM-LOADING CAPACITY

<u>Method</u>	<u>Loaded Resin</u>		<u>As-received Resin</u>	
	<u>Bq/g</u>	<u>Bq/cm³</u>	<u>Bq/g</u>	<u>Bq/cm³</u>
1	6,400	1,920	6,280	1,445
2	7,000	2,100	6,870	1,580
3	7,550	2,265	7,390	1,700

- Methods:
1. Analysis of the loaded resin in the bottom third of Key Lake Column No. 1 at test completion.
 2. Extrapolation of resin radium analysis and radiation levels of Key Lake Column No. 1 after extended shut-down.
 3. Extrapolation of radium mass balances and radiation levels measured on Key Lake Column No. 1 during operating period.

Note: These radium-loading values are only applicable to the type of Key Lake water used in the test. Actual radium loading would be expected to vary with the type of water treated.

The radiation exposure potential of loaded resin under operating conditions was estimated at 0.1 mR/h at a distance of 122 cm from the outside wall of a full-scale resin column containing approximately 6 m³ of loaded resin. An increase in radiation to approximately 6 mR/h would occur if the loaded resin remained in the column under static conditions for several weeks after shutdown. Under normal operating conditions it appears the anticipated dose rates would be below allowable limits although further information would be required in order to be more definitive with regards to the radiation exposure potential of loaded resin.

The disposal of the loaded resin after use could be of concern due to the potential for high radium levels in a relatively small concentrated mass. At an operating uranium mine the resin could be discharged to the tailings area as an admixture with the neutralized mill tailings. Alternative disposal methods would include solidification with cement, bitumen, glass or modified vinyl ester resins prior to containment in a suitable radioactive storage facility.

Conclusions and Recommendations

The laboratory investigations have shown that the radium-selective complexer, Dowex XFS 43230.00, is efficient in removing radium from contaminated water. The resin efficiency does not appear to be affected by the radium concentration in the contaminated water being treated although the service life of the resin in terms of bed volumes of water treated would be restricted due to a finite loading capacity of the resin as well as the chemistry of the water being treated. The service life of the resin would also depend on the number of resin columns being used since levels of less than 0.37 Bq/L Ra-226 (total) would need to be maintained in the final discharge.

The radium removal efficiency of the resin is not affected by high concentrations of calcium in the water being treated, but lower loading capacity, and hence shorter service life, can be expected for treatment of tailings decant water which has been previously neutralized with lime.

The chemistry of the water being treated would appear to be the dominating factor governing the radium removal efficiency of the resin in terms of discharge quality as well as resin loading capacity. The discharge results seemed to indicate that resin poisoning could occur in a treatment operation where the efficiency and loading capacity of the resin could be restricted in a sequential operation of several resin columns in series. Further work is required in order to define this potential concern in terms of design requirements.

Capital and operating cost estimates of a treatment facility utilizing the radium-selective ion exchange complexer for radium removal have shown that the resin treatment process would be similar in costs to a barium chloride/sand filtration system of radium removal. The capital costs were estimated at \$2,731,400 for the resin treatment and \$3,188,600 for the barium chloride process with operating costs estimated at \$0.45/m³ and \$0.40/m³ respectively. However, the costs of a conventional barium chloride/settling pond system would be expected to be substantially lower than either of these options.

The result of this test program have identified other aspects which would warrant further investigations for any radium removal process using the radium-selective complexer. The service life of the resin should be defined in terms of the capacity of the resin in a lead column for two or three-column systems where final discharge water is maintained below regulatory requirements. The radium removal efficiency of resin in a sequential operation should be determined in light of potential resin poisoning effects.

It would also be worthwhile to determine the radium removal efficiencies of downflow columns on contaminated water containing levels of suspended solids typical of minewater from operating mines. This would seem necessary since the tests in this program were operated under upflow conditions with relatively clear contaminated water.

From an economic aspect, studies should be undertaken to determine the potential for regenerating loaded resin along with evaluating the efficiency of the regenerated resin. From a practical standpoint however it appears

that the application of the resin for treating contaminated water would be best suited as a single usage with loaded resin being discarded rather than being eluted for potential re-use.

The long-term stability of loaded resin should be defined in terms of the potential for re-dissolution of the adsorbed radium as well as the effect of resin degradation on radium stability.

RADIUM REMOVAL FROM
CANADIAN URANIUM MINING EFFLUENTS
BY A RADIUM-SELECTIVE
ION EXCHANGE COMPLEXER

1.0 INTRODUCTION

The possible applicability of a radium-selective ion exchange complexer for removing radium from Canadian uranium mining effluents had been identified and discussed as a possible alternative to present radium removal methods⁽¹⁾. Work by other workers^(2,3) has shown that this complexer is very efficient in removing radium from contaminated water. Also, plant trials on contaminated minewater at the Mt Taylor uranium mine in New Mexico is reported to have shown that the resin complexer was efficient in removing radium under plant operating conditions.

As a result, a laboratory test program was initiated by the Department of Energy, Mines and Resources as part of the National Uranium Tailings Program to investigate the suitability of this resin for Canadian uranium mining effluents. The test program was carried out by Melis Consulting Engineers Ltd. (MCEL) under contract to the Department of Supply and Services using the Saskatchewan Research Council (SRC) facilities located in Saskatoon, Saskatchewan.

The main objectives of the test program were as follows:

- determine the loading capacity and loading characteristics of the radium-selective complexer on tailings pond decant water typical of Elliot Lake uranium operations and on contaminated water from a northern Saskatchewan uranium operation utilizing layered tailings disposal
- suggest methods of resin disposal and equipment decontamination
- measure radiation levels and determine the radiation exposure potential of loaded resin
- present a brief economic comparison of conventional methods of radium removal with a process of removing radium by using the radium-selective ion exchange complexer.

The radium-selective complexer evaluated was an ion exchange resin manufactured by the Dow Chemical Company under the trade name of "Dowex XFS 43230.00". This complexer was evaluated using two types of uranium mining effluents:

- tailings decant water from Rio Algom Ltd.'s Panel uranium mine located in Elliot Lake, Ontario and
- minewater from the Key Lake uranium mine located in northern Saskatchewan which was collected as grinding circuit water from the mill process.

Initially it was expected that seepage and runoff solution from the layered tailings area at Key Lake could be used but this was not possible due to bulk sampling difficulties. Consequently it was agreed that contaminated process water from the grinding circuit would be used since this could be sampled with relative ease.

2.0 SUMMARY OF RESULTS

The testwork for evaluating the radium-selective ion exchange complexer was carried out using two separate test units in order to accommodate the two different types of contaminated water used in the testwork. The test procedures involved pumping the feed water through three resin columns in series and analysing weekly discharge samples for radium to provide a measurement of radium removal efficiency for the Dowex XFS 43230.00 resin.

The operating parameters for both the Panel and Key Lake test units are summarized in Table 2-1. Under these conditions no operating problems were encountered during the course of the test program. The average feed concentration of the bulk sample of Panel tailings decant water was 6.7 Bq/L Ra-226 (diss.). The Key Lake grinding circuit water analysis averaged 60.0 Bq/L Ra-226 (diss.) for the total bulk sample.

The physical characteristics of the resin, as measured during the course of the testwork, are summarized in Table 2-2. A significant loss of volume on the as-received resin was noticed in both test units. Since the resin is supplied in the sodium form, a volume loss of approximately 25% can be expected when the resin is placed in service as a result of an exchange of calcium ions for sodium ions in the resin.

Measurements of specific flowrates for various bed expansions showed that a specific flowrate of $33 \text{ m}^3/\text{h}/\text{m}^2$ was required to achieve 100% bed expansion of the resin during operation. Radium analysis of discharge solutions indicated that the radium removal efficiency of the resin was not affected by operating at 100% bed expansion for the type of water tested (Panel tailings decant water).

Radium analysis of the lead column discharges in each set showed a gradual increase in radium concentration for both the Panel and Key Lake tests. These assays are graphically presented in Figure 2-1. The more rapid increase in radium concentration for the Key Lake test is due to

TABLE 2-1

TEST OPERATING PARAMETERS(1)

	<u>Panel</u>	<u>Key Lake</u>
Diameter of column (cm)	1.27	1.905
Wet settled resin bed height in each column (cm)	55.0	73.8
Expanded bed height (cm)	74.5	95.5
Bed expansion (%)	35	29
Volume loss on as-received resin (%)	24.8	22.4
Flowrate - mL/min	35	56
- bed volume/min(2)	0.50	0.27
- $m^3/h/m^2$	16.6	11.8
- USGPM/ft ²	6.8	4.8
Total water treated through resin columns (kg)	4,832	4,564
Total operating time (days)	92	58
Radium concentraton in feed (Bq/L Ra-226(diss.))	6.7	60.0
Temperature (°C)	20-25	20-25

(1) Data given is for Column No. 1. Column No. 2 and No. 3 conditions were similar.

(2) based on settled bed height during operation

TABLE 2-2RESIN PHYSICAL CHARACTERISTICS

Bulk density of wet settled resin - as received (g/cm^3)	0.84
Moisture of drained settled resin - as received (%)	72
Dry resin per unit volume of wet settled resin (g/cm^3)	
- as received	0.23
- after calcium exchange	0.30
Specific flowrate for 100% bed expansion ($\text{m}^3/\text{h/m}^2$)	33
Resin terminal velocity (cm/sec)	2.5
Voidage value, e , at 100% bed expansion	0.69
Mesh size	20 x 50
Physical appearance	uniform beads

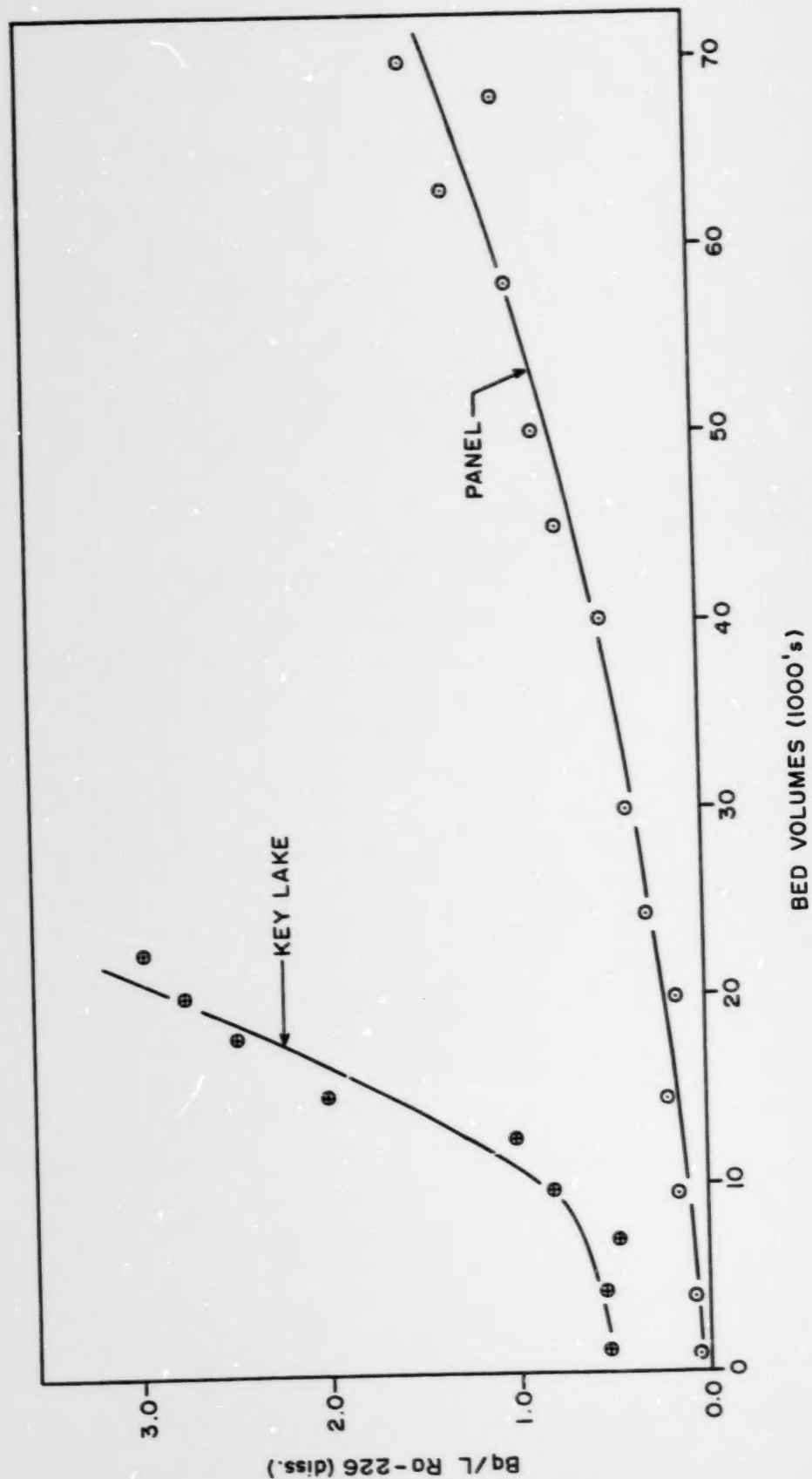


FIG. 2-1 COLUMN NO. 1 DISCHARGE ANALYSIS VS. BED VOLUMES OF WATER TREATED

the much higher radium concentration in the Key Lake water as compared to the Panel water sample.

A comparison of the Column No. 1 discharge radium analysis as a percentage of the feed concentration is shown in Figure 2-2 for the Panel and Key Lake tests. From this graph it appears that full resin loading in Column No. 1 would have first occurred in the Key Lake test in terms of bed volumes of water treated due to the higher radium content in the Key Lake water.

The discharge radium analyses of Columns No. 2 and No. 3 in each set were not significantly different during the column operation with the level in No. 3 Column discharge in either test unit only increasing to 0.2 Bq/L Ra-226 (diss.) after treatment of 69,350 bed volumes of Panel tailings decant water and 21,700 bed volumes of Key Lake grinding water.

A summary of water analyses is provided in Table 2-3 for the feed to the Panel and Key Lake sets and the discharge of Column No. 3 for each set at test completion. An analysis of the loaded resin for each test along with analysis of new resin is provided in Table 2-4. These results show that the radium-selective complexer is efficient in removing only radium from uranium mining effluents. The Key Lake results did indicate some removal of uranium but the discharge level was still higher than the regulatory requirement of 1.0 mg/L U. The lower level of arsenic in the Key Lake discharge was thought to be due to the formation of a small amount of precipitate above the resin in Key Lake Column No. 1 and not as a result of adsorption on the resin which is evident from the low arsenic value on the loaded resin. The apparent increase in zinc concentrations for both the Panel and Key Lake discharge samples was likely due to the use of brass fittings in the test equipment.

The radium removal efficiencies for the first column in each set are

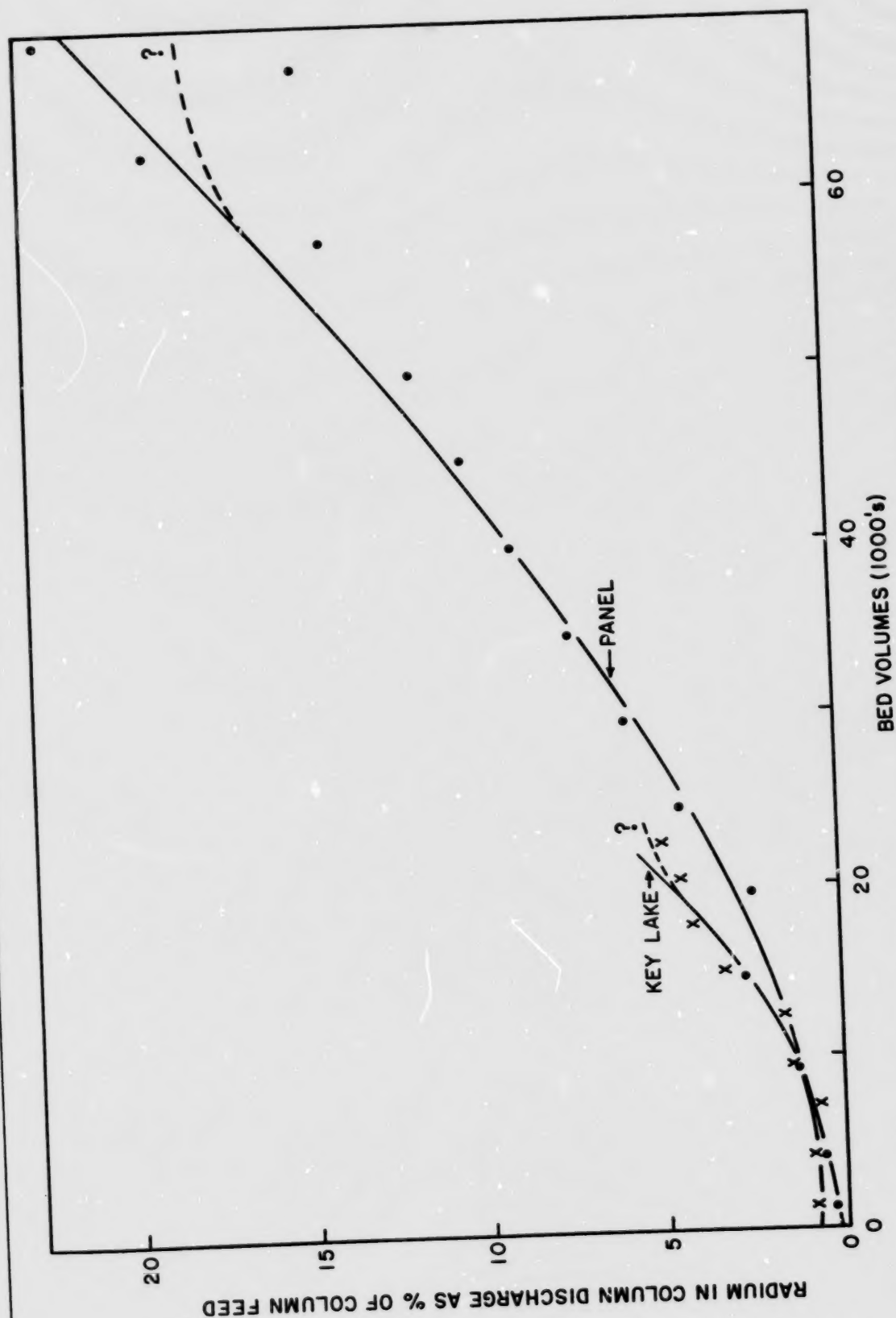


FIG.2-2 COLUMN NO.1 DISCHARGE RADIUM ANALYSES AS PERCENT OF FEED

TABLE 2-3

FEED AND DISCHARGE ANALYSES

<u>Element</u> <u>Bq/L</u>	<u>Panel</u>		<u>Key Lake</u>	
	<u>Feed(1)</u>	<u>Discharge(2)</u>	<u>Feed(1)</u>	<u>Discharge(2)</u>
Ra-226 (total)	6.7	0.20	60.0	0.25
Ra-226 (diss.)	6.7	0.20	60.0	0.19
<u>mg/L</u>				
U	0.19	0.21	2.3	1.1
Al	0.13	1.3	0.076	0.059
Ba	0.046	0.087	0.038	0.12
Ca	400	335	38	61
Mg	13	19	36	35
Na	58	91	11	12
K	85	149	20	20
Co	0.013	0.015	0.024	0.022
Cr	0.010	0.002	0.008	0.005
Cu	0.084	0.077	0.017	0.037
Fe	0.50	0.076	0.35	0.23
Mn	0.28	0.32	0.18	0.19
Mo	< 0.005	< 0.005	0.43	0.39
Ni	0.056	0.093	13	11
Zn	0.11	0.79	0.086	0.17
As	0.003	-	1.0	0.29
TSS	2	2	4	4
TDS	2,500	2,500	578	550
SO ₄	1,390	-	238	-
pH	4.8		5.1	

(1) Analysis of feed sample from first batch treated.

(2) Analysis of grab discharge sample at test completion.

TABLE 2-4

RESIN ANALYSES ($\mu\text{g/g}$ dry basis)

<u>Element</u>	<u>New Resin</u>	<u>Loaded Resin</u>	
		<u>Panel</u>	<u>Key Lake</u>
		<u>No. 1 Column</u>	<u>No. 1 Column</u>
Ra-226 (Bq/g)	<1	1,200	4,064
U	-	8	359
Al	28	560	19
Ba	1,800	2,700	2,100
Ca	300	55,700	33,500
Mg	20	1,600	13,800
Na	60,000	640	260
Co	5	5	14
Cr	300	270	410
Cu	6	36	23
Fe	590	1,400	800
Mn	26	42	95
Mo	<4	<4	92
Ni	200	100	5,800
Zn	40	62	59
As	<1	-	360

summarized in Table 2-5. In both sets there was a gradual decrease in radium removal efficiency which was directly related to the number of bed volumes of water treated. This drop in efficiency is shown graphically in Figure 2-3. Radium removal efficiency in the lead column for the Panel test dropped from 99.0% to 81.3% after treatment of 69,350 bed volumes of water. The efficiency of the lead column in the Key Lake test dropped from 99.1% to 95.4% after treatment of 21,700 bed volumes of water. The cumulative radium removal efficiency in the lead column for the total water treated was 91.5% for the Panel test and 97.7% for the Key Lake test.

The average radium removal efficiency of the second column of each set during the total operating period was 79% and 86% for the Panel and Key Lake tests respectively. Column No. 3 efficiency was calculated as 25% and 7% respectively.

A summary of the radium analysis of the resin in each column at test completion is given in Table 2-6. The higher radium concentration of the resin in the bottom of the lead column for the Key Lake test was due to a certain degree of segregation occurring in the column at the flow-rate used in the test (29% bed expansion).

Since it was not possible to continue the test program to achieve saturation of the resin in the lead column for either test, an estimate of the ultimate radium-loading capacity of the resin was accomplished by extrapolating the available data from the testwork. This estimate was compared to the radium analysis of the resin in the bottom third of Key Lake Column No. 1 which was thought to be approaching saturation in terms of radium loading.

TABLE 2-5

COLUMN No. 1 EFFICIENCIES

<u>Batch No.</u>	<u>Panel</u>				<u>Key Lake</u>			
	<u>Bed Volumes Treated</u>		<u>% Ra Removal</u>		<u>Bed Volumes Treated</u>		<u>% Ra Removal</u>	
	<u>Batch</u>	<u>Cumulative</u>	<u>Batch</u>	<u>Cumulative</u>	<u>Batch</u>	<u>Cumulative</u>	<u>Batch</u>	<u>Cumulative</u>
1	13,400	13,400	99.0	99.0	4,030	4,030	99.1	99.1
2	14,936	28,336	96.3	97.5	4,351	8,381	99.1	99.1
3	14,197	42,533	92.5	95.9	4,851	13,232	98.4	98.8
4	12,703	55,236	88.1	94.1	4,353	17,585	96.5	98.3
5	14,114	69,350	81.3	91.5	4,102	21,687	95.4	97.7

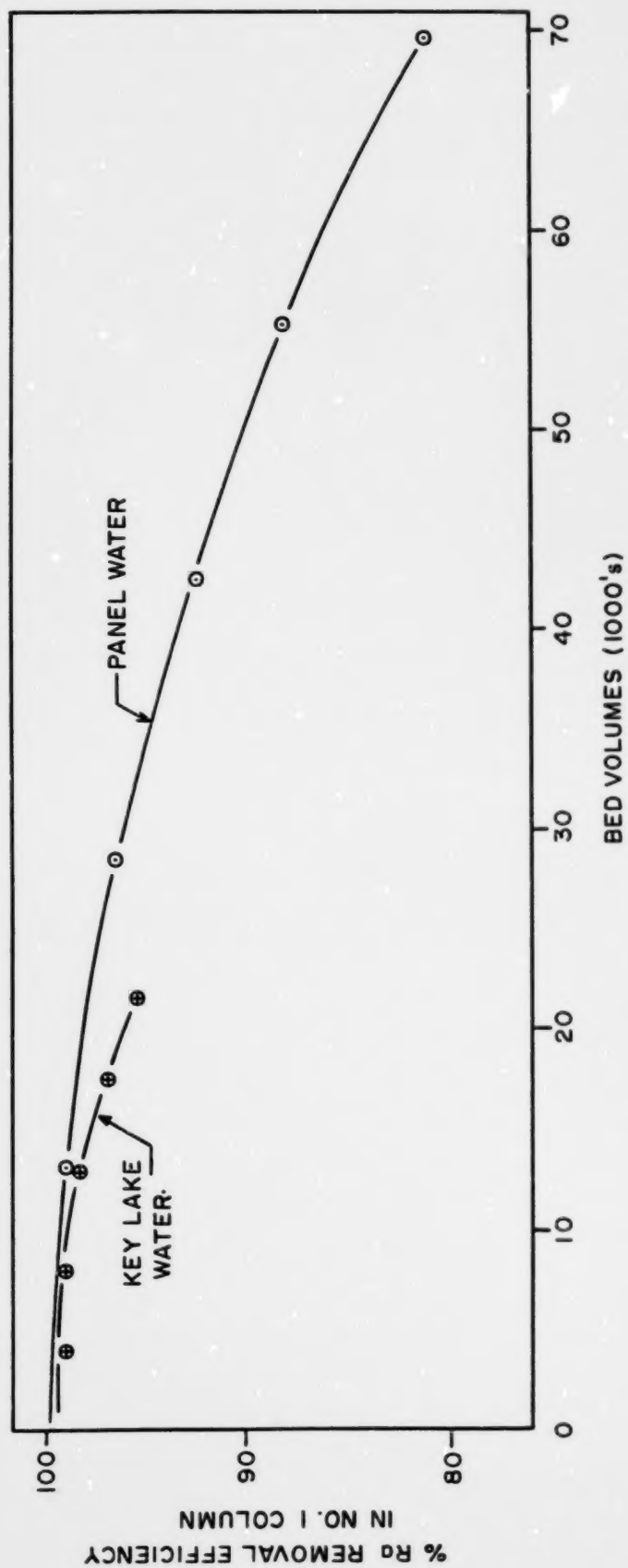


FIG.2-3 BATCH RADIUM REMOVAL EFFICIENCY IN NO.1 COLUMN VS BED VOLUMES OF WATER TREATED

TABLE 2-6RESIN ANALYSIS SUMMARY (Bq/g)

	<u>Panel</u>	<u>Key Lake</u>
Column No. 1 - average	1,200	4,064
- top third	-	1,800
- middle third	-	3,900
- bottom third	-	6,400
Column No. 2	88	48
Column No. 3	3.7	5.4

The radium-loading values determined for the resin are summarized in Table 2-7.

The ultimate loading capacity of the resin was estimated as 2,100 to 2,265 Bq/cm³ of wet settled loaded resin. This would be equivalent to 1,580 to 1,700 Bq/cm³ (1.2 to 1.3 mCi/ft³) of new wet settled resin due to the volume loss that occurs when the resin is put into service. This loading capacity would of course be dependent on the chemistry of the contaminated water being treated. The results of the Panel test indicates that lower resin loadings should be expected when treating effluents containing high levels of calcium.

The radiation exposure potential of loaded resin was estimated by calculating expected radiation dose rates for a full-scale operation with resin loading of 6,400 Bq/g Ra-226. The radiation dose rate during operation of a column was estimated at 0.26 mR/h, 0.10 mR/h and 0.05 mR/h at a distance of 50 cm, 122 cm, and 200 cm from the outside wall of a resin column containing approximately 6 m³ of loaded resin. This radiation would increase to 6 mR/h if the loaded resin remained under static conditions several weeks after column shutdown since there would be a gradual build-up of radiation due to the build-up of radon daughters as a result of the natural decay of radium.

The capital costs of a 150 m³/h treatment facility utilizing the radium-selective ion exchange complexer have been estimated at \$2,731,400 in mid-1984 Canadian dollars. Operating costs were estimated at \$569,065 per year or \$0.45/m³ of water treated. These costs are similar to the costs of radium removal by a barium chloride/sand filtration system.

TABLE 2-7

RESIN RADIUM-LOADING CAPACITYRa-226 Loading

<u>Method</u>	<u>Loaded Resin</u>		<u>As-received Resin</u>	
	<u>Bq/g</u>	<u>Bq/cm³</u>	<u>Bq/g</u>	<u>Bq/cm³</u>
1	6,400	1,920	6,280	1,445
2	7,000	2,100	6,870	1,580
3	7,550	2,265	7,390	1,700

- Methods:
1. Analysis of the loaded resin in the bottom third of Key Lake Column No. 1 at test completion.
 2. Extrapolation of resin radium analysis and radiation levels of Key Lake Column No. 1 after extended shutdown. See Section 3.3.5.
 3. Extrapolation of radium mass balances and radiation levels measured on Key Lake Column No. 1 during operating period. See Section 3.3.5.

3.0 LABORATORY TESTWORK

3.1 Sample Description

3.1.1 Radium-Selective Complexer

A sample of the complexer, Dowex XFS 43230.00, was obtained for the testwork from Dow Chemical Canada Inc., Sarnia, Ontario. A material safety data sheet for the resin complexer provided by the manufacturer is included in Appendix A. The physical properties of the resin determined as part of the test evaluations are given in Table 3-1.

A plasma scan analysis was performed on the as-received resin in order to obtain a reference analysis of the resin for identifying its loading characteristics during treatment of water for radium removal. This resin analysis is detailed in Table 3-2. As can be seen from this analysis the resin is supplied in the sodium form and contains a significant amount of barium.

3.1.2 Water Samples

The two types of uranium mining effluents selected to evaluate the radium removal efficiency of the resin are described below.

The first type of water obtained was tailings pond decant water from the Panel Mine operations of Rio Algom Ltd. in Elliot Lake, Ontario, which processes a uranium ore containing 0.1% U_3O_8 . In this operation the mill tailings are bulk-neutralized to pH 10.5 with lime prior to discharge to the tailings pond. Tailings pond decant water, which is slightly acidic (pH 5) due to the presence of oxidized pyritic tailings in the tailings area, is treated with lime and barium chloride for radium removal prior to discharge.

The bulk sample of water obtained for test purposes was collected from the feed line to the radium precipitation circuit on January 24, 1984. Twenty-five 220 L plastic barrels, containing a total

TABLE 3-1PHYSICAL PROPERTIES OF DOW RADIUM-SELECTIVE COMPLEXER

Trade Name	Dowex XFS 43230.00
Mesh Size	20 x 50
% moisture (wet settled resin)	72
Bulk density (wet settled resin)(g/cm ³)	0.84
Dry resin per unit volume of wet settled resin (g/cm ³)	
- as received	0.23
- after calcium exchange	0.30
% volume loss due to calcium exchange in operation	25
Physical appearance	uniform beads

TABLE 3-2RESIN COMPLEXER ANALYSIS(as received)

<u>Element</u>	<u>µg/g dry resin(1)</u>	<u>Element</u>	<u>µg/g dry resin</u>
B	<10	Mg	20
P	<40	Mn	26
Al	28	Mo	< 4
Ba	1,800	Na	60,000
Be	< 1	Ni	200
Ca	300	Pb	< 4
Cd	< 1	Ti	< 1
Co	5	V	< 10
Cr	300	W	< 4
Cu	6	Zn	40
Fe	590	As	< 1
U	-	Ra	< 1

(1) resin dried to constant weight at 65°C

of 4,860 L of tailings decant water, were shipped by heated truck from the mine and arrived at the SRC pilot plant building in Saskatoon, Saskatchewan on January 20, 1984.

The second type of water used for the testwork was grinding circuit process water from the Key Lake mining operation in northern Saskatchewan. The ore processed in this operation is a high-grade uranium ore (2.5% U_3O_8) containing substantial concentrations of arsenic and heavy metals. Initially it was anticipated that seepage and runoff from the Key Lake tailings area could be used for the testwork but due to bulk sampling difficulties it was only possible to obtain contaminated process water from the neutral thickener overflow in the grinding circuit. Although the process water used in the grinding circuit at Key Lake is minewater the sample of water collected would be expected to be higher in radium contamination than typical minewater since it has been in contact with the ore during the comminution process.

The bulk sample of water was collected from the neutral thickener overflow tank in the Key Lake grinding plant on February 9, 1984. A total of twenty-five 220 L plastic barrels containing 4,590 L of Key Lake grinding circuit water was shipped by truck and received at the SRC pilot plant on February 14, 1984. The water was partially frozen (slush) when received.

A full analysis of each bulk sample of water is presented in Table 3-3. As expected the Key Lake water is much higher in radium content than the Panel water since the Key Lake water has been in contact with a high-grade uranium ore and hence higher radionuclide levels could be anticipated.

The high nickel, and to a lesser extent arsenic, content of the Key Lake water is a reflection of the substantial concentration of nickel and arsenic in the Key Lake ore. The higher calcium and sulphate concentrations in the Panel water are due to the neutralization of acidic slurries from the mill process with lime prior to disposal to the tailings area.

TABLE 3-3
CONTAMINATED WATER ANALYSIS

<u>Element</u> <u>Bq/L</u>	<u>Panel Mine</u> <u>Tailings Decant Water</u>	<u>Key Lake</u> <u>Grinding Circiut Water</u>
Gross α	14	90
Gross β	17	40
Pb-210 (total)	0.25	1.3
Pb-210 (diss)	0.15	0.15
Po-210 (total)	< 0.005	1.1
Ra-226 (total)	6.7	60
Ra-226 (diss)	6.7	60
Th-227 (total)	0.1	0.02
Th-227 (diss)	0.07	0.04
Th-228 (total)	0.09	0.35
Th-228 (diss)	0.05	0.06
Th-230 (total)	0.16	1.2
Th-230 (diss)	0.04	0.35
Th-232 (total)	0.3	0.3
Th-232 (diss)	0.01	0.08
<u>mg/L</u>		
U (total)	0.19	2.3
U (diss)	0.17	1.8
B	0.25	0.3
P	< 0.05	0.1
Al	0.13	0.076
Ba	0.046	0.038
Be	< 0.001	< 0.001
Ca	400	33
Cd	< 0.001	0.001
Co	0.013	0.024
Cr	0.010	0.008
Cu	0.084	0.017
Fe	0.50	0.35
K	85	20
Mg	13	36
Mn	0.28	0.18
Mo	< 0.005	0.43
Na	58	11
Ni	0.056	13
Pb	< 0.005	< 0.005
Ti	< 0.001	< 0.001
V	0.01	0.02
W	< 0.005	< 0.005
Zn	0.11	0.086
As	0.003	1.0
TSS	2	4
TDS	2,500	578
SO ₄	1,390	238
NH ₄	5.8	2.7
Kjeld.N	6.8	4.5
Acidity	13	8
pH (avg)	4.8	5.1

The pH value given for both types of water is an average value of the measurements taken during the test program. Individual pH measurements are provided in Table 3-4. The high pH reading for the February 20 feed sample of the Key Lake water is an anomalous value when compared to the other measurements taken.

In summary, the two types of contaminated water received for test purposes were thought to be quite suitable as feed samples due to the different concentration of radium in each sample as well as the different chemical make-up of each type. The Panel tailings decant water, containing 6.7 Bq/L Ra-226 (diss.), can be considered as typical of Elliot Lake operations with the only exception being the pH of the tailings decant water which varies from acidic to neutral between the different milling operations in Elliot Lake. The Key Lake water, containing 60 Bq/L Ra-226 (diss.), can be considered as representative of contaminated water which has been in contact with uranium ores containing arsenic and heavy metals. The radium concentration is likely higher than normal due to this sample of water having been in contact with the ore in the grinding circuit.

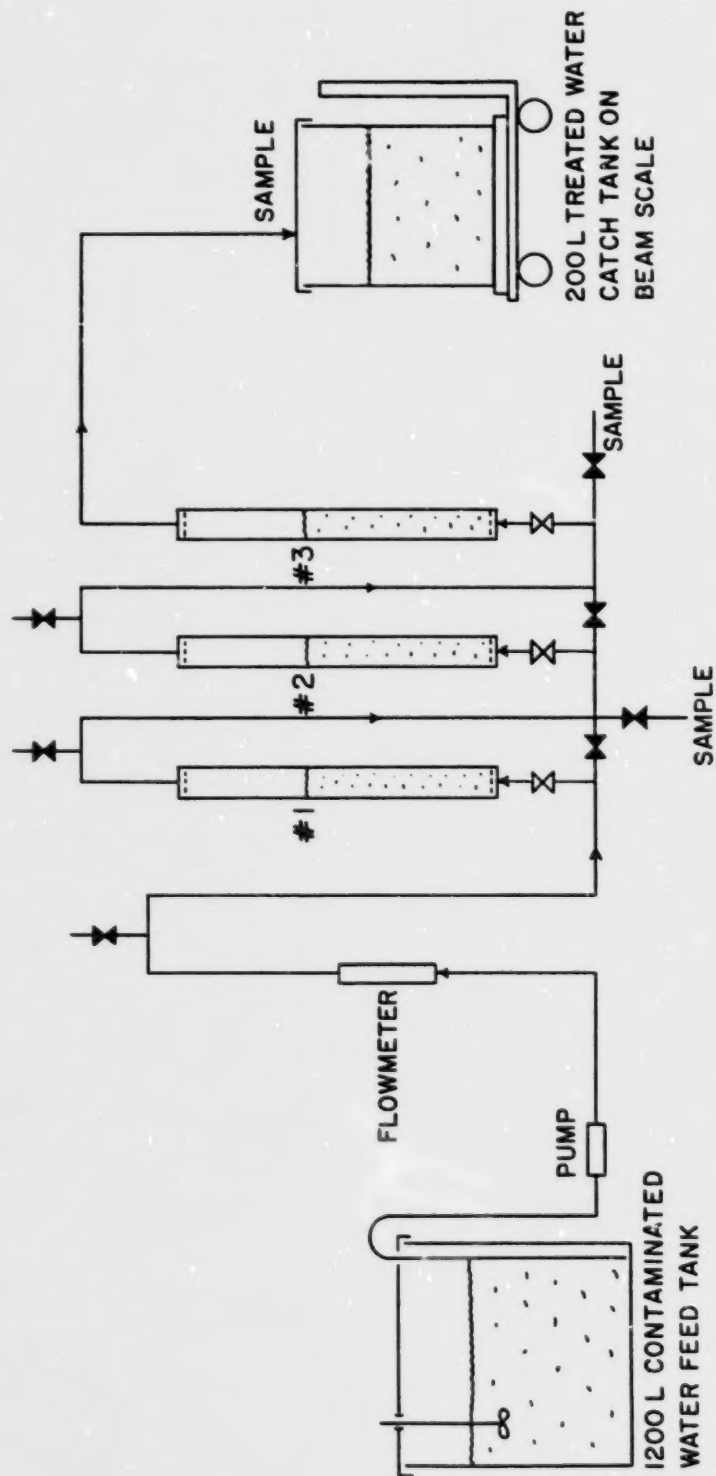
With these two bulk samples the radium-selective complexer could therefore be tested with water of varying chemistry and different radium concentrations in order to determine its radium-loading characteristics on two different types of contaminated water with the most significant difference between the two being calcium content.

3.2 Test Methodology

Two separate sets of columns (C-Acrylic tubing) were fabricated in order to carry out the test program concurrently on the two samples. The test apparatus and flowsheet are shown in Figure 3-1. Photographs of the test equipment are shown in Plates No. 1 and No. 2. The columns in the foreground in Plate No. 1 are the Panel columns and the columns in the foreground in Plate No. 2 are the Key Lake columns. The test equipment was identical for both the Panel and Key Lake units with the only exception

TABLE 3-4
pH MEASUREMENTS ON FEED SAMPLES

<u>Water</u>		<u>pH</u>
Key Lake	February 20, 1984	6.8
	March 6, 1984	4.8
	March 10, 1984	4.5
	March 19, 1984	4.5
	March 20, 1984	5.3
	March 26, 1984	4.9
Panel	February 10, 1984	5.4
	February 20, 1984	4.7
	March 6, 1984	4.9
	March 11, 1984	4.3
	March 19, 1984	4.7
	March 22, 1984	4.3
	March 26, 1984	4.6



PANEL COLUMNS: 1.27 cm diam. x 1.83 m high

KEY LAKE COLUMNS: 1.905 cm diam x 1.83 m high

FIG. 3-1 TEST APPARATUS

being the size of the resin columns. The Panel set was made up with three 1.27 cm (0.5 inch) diameter by 183 cm columns in series while the Key Lake set included three 1.91 cm (0.75 inch) diameter by 183 cm columns in series. Although filters were included for possible clarification of the feed they were not used since both types of water tested contained low levels of suspended solids (2 to 4 mg/L).

Larger columns were used for the Key Lake test since the higher radium content of the Key Lake water was thought to possibly require more resin in order to ensure efficient removal of radium from the complete bulk sample of Key Lake water. Consequently a larger amount of resin was used as a safeguard since the loading capacity of the resin was unknown at the beginning of the test program.

In order to accommodate the size of test equipment each bulk sample of water was divided into five batches of five barrels each with the complete bulk sample being treated in five equal batches. Mass and radium balances were accomplished by recording the weights of feed and discharge solutions as well as the various samples taken during the test operations. Samples were collected threetimes per week from the discharge of the three columns in each set with only the Monday samples of each week being submitted for dissolved Ra-226 analysis.

The columns were operated under upflow conditions with the contaminated water flow controlled by a peristaltic pump and flowmeter on the feed line. The flowrate of water through the resin columns was maintained at 35 mL/min for the Panel unit and at 56 mL/min for the Key Lake set. The operating parameters of Column No. 1 in the Panel and Key Lake sets are detailed in Table 3-5. Operating conditions for Columns No. 2 and No. 3 were similar to Column No. 1 for each set. A lower specific flowrate for the Key Lake unit was selected at the onset of the program in order to accommodate the higher radium content of this water in terms of the unknown radium removal efficiency of the resin.

The water discharging from the resin columns was collected in the plastic barrels and retained for removal of remaining contaminants in order to meet City of Saskatoon discharge guidelines.

TABLE 3-5

OPERATING PARAMETERS FOR PANEL AND KEY LAKE COLUMN NO. 1(1)

	<u>Panel</u>	<u>Key Lake</u>
Diameter of column (cm)	1.27	1.905
Dry resin mass in column (g)	21.4	61.2
Wet settled bed height, initial (cm)	73.1	95.1
Wet settled bed height during operating period (cm)	55.0	73.8
Volume loss on as-received resin (%)	24.8	22.4
Expanded bed height during operation (cm)	74.5	95.5
Bed expansion during operation (%)	35	29
Flow (mL/min)	35 [±] 1	56 [±] 1
Flow (bed volume/min)(2)	0.50	0.27
Specific flowrate (m ³ /h/m ²)	16.6	11.8
Specific flowrate (USGPM/ft ²)	6.8	4.8
Retention time in bed (min)	1.5	2.5
Temperature (°C)	20-25	20-25

(1) Column No. 2 and No. 3 operating parameters were similar to Column No. 1

(2) Based on settled bed height during operating period

After loading the columns with resin and operating for approximately twenty-four hours, measurements of the wet settled resin bed height indicated that a volume loss in the resin bed had occurred in both test units. Measurements of bed heights during the operating period indicated a total volume loss per column of 24.8% for the Panel test and 22.4% for the Key Lake test. This volume loss on the resin as-received was due to the resin being in the sodium form when received from the manufacturer (see Table 3-2) and during its initial use the sodium ions are exchanged for calcium ions present in the water. The higher calcium content (400 mg/L Ca) in the Panel water (Table 3-3) caused the volume loss to occur in the first twenty-four hours of operation for the Panel test. In the Key Lake test the majority of volume loss occurred within the first twenty-four hours with a slight decrease continuing over the first week of operation.

The resin bed expansion during operation was 35% for the Panel test and 29% for the Key Lake test. At this bed expansion, the flowrate through the resin columns for the Panel and Key Lake tests, based on the settled bed height during the operating period, was 0.50 bed volume per minute and 0.27 bed volume per minute respectively. This was equivalent to a retention time in the bed of 1.5 minutes for the Panel test and 2.5 minutes for the Key Lake test. Under these conditions the specific flowrate was $16.6 \text{ m}^3/\text{h}/\text{m}^2$ ($6.8 \text{ USGPM}/\text{ft}^2$) for the Panel unit and $11.8 \text{ m}^3/\text{h}/\text{m}^2$ ($4.8 \text{ USGPM}/\text{ft}^2$) for the Key Lake set.

The fluidization characteristics of the resin were determined by taking measurements of bed expansion of the resin in No. 1 Column of the Panel set for various specific flowrates. The results are listed in Table 3-6 and depicted in Figure 3-2. From these results the specific flowrate for 100% bed expansion of the resin was determined as $33 \text{ m}^3/\text{h}/\text{m}^2$ ($13.5 \text{ USGPM}/\text{ft}^2$). This value confirmed the specific flowrate determined by Dow Chemical Company workers in earlier work on the resin⁽²⁾.

The fluidization characteristics of the resin are shown in Figure 3-3 where voidage, e , defined as:

TABLE 3-6

PANEL COLUMN NO. 1 INCREASED FLOWRATE DATA (1)

Day of Operation	Flow (mL/min)	Specific Flowrate		Bed Expansion (%)	Liquid Superficial	Voidage e
		$(\text{m}^3/\text{h}/\text{m}^2)$	$(\text{USGPM}/\text{ft}^2)$		Velocity, V_s (cm/s)	
69	35	16.6	6.8	34	0.46	0.54
70	103.5	49	20.0	203	1.36	0.80
71	80	38	15.5	126	1.05	0.73
72	59	28	11.5	78	0.78	0.65

(1) Column No. 2 and No. 3 flowrates were the same as Column No. 1.

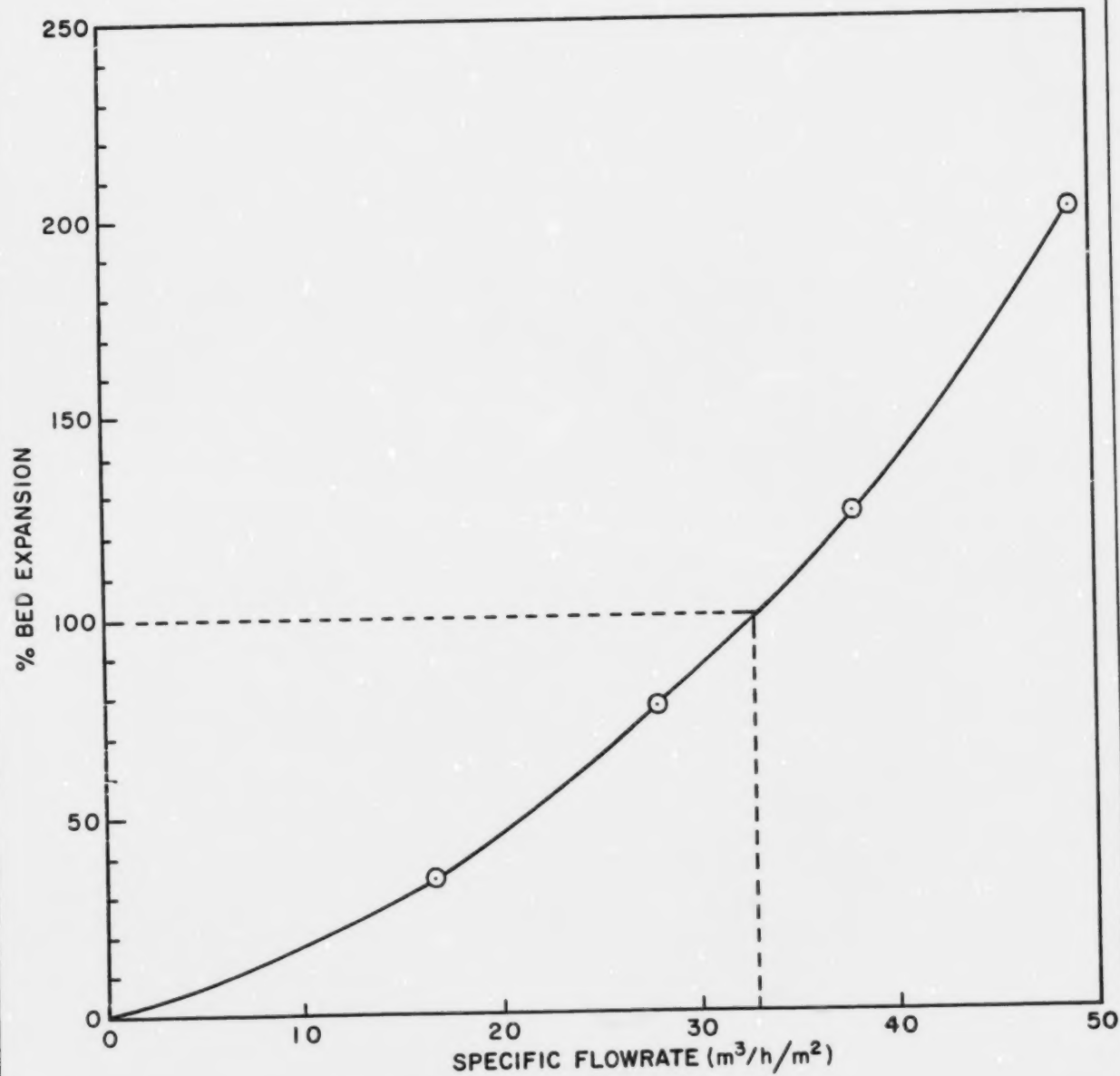


FIG.3-2 BED EXPANSION VS SPECIFIC FLOWRATE

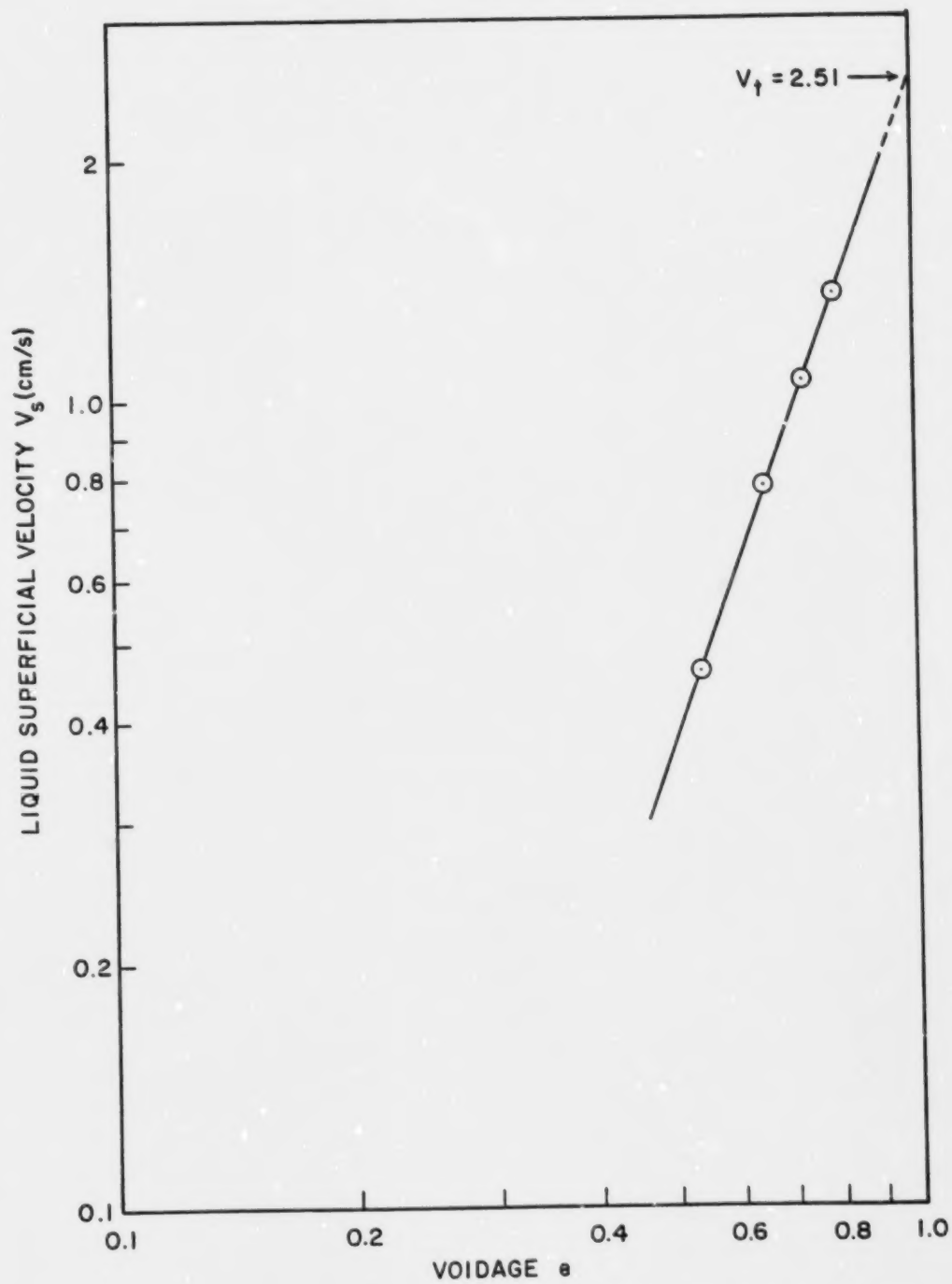


FIG. 3-3 FLUIDIZATION CHARACTERISTICS OF DOWEX
XFS 43230.00 RESIN

$$\frac{h_0}{h} = \frac{1-e}{0.62}$$

where h_0 = static bed height

h = operating bed height

was plotted against the liquid velocity, V_s .

At 100% bed expansion ($h=2h_0$) the voidage value is 0.69 and the superficial velocity, V_s , is 0.92 cm/s. By extrapolation the resin terminal velocity, V_t , was determined as 2.5 cm/s.

3.3 Test Results

3.3.1 Water Analyses

The Panel test was operated continuously at 35 mL/min from January 31, 1984 to May 2, 1984 for a total of 92 days of continuous operation. A total of 69,350 bed volumes of water were treated during the period. Ra-226 analyses for the test period are listed in Table 3-7.

The average feed concentration of the Panel tailings decant water bulk sample was 6.7 Bq/L Ra-226 (diss.). The radium levels in Column No. 1 discharge are plotted in Figure 3-4 in terms of bed volumes of water treated. The level of radium in the discharge of the first column increased slowly from 0.03 Bq/L Ra-226 (diss.) at the start of the test to 1.5 Bq/L Ra-226 (diss.) after a total of 69,350 bed volumes of water were treated.

The discharge of Column No. 3 increased gradually from 0.01 Bq/L Ra-226 (diss.) to a value of 0.2 Bq/L Ra-226 (diss.) after 69,350 bed volumes. Taking into account the accuracy of the radium-226 analytical method (given in Appendix B) there does not appear to be any significant difference in solution assays for Columns No. 2 and No. 3 discharges. The results of Columns No. 2 and No. 3 discharges are plotted in Figure 3-5 in terms of bed volumes of water treated.

TABLE 3-7
PANEL TEST-DISSOLVED RADIUM-226 ANALYSES (Bq/L)

Days of Operations	Date Sampled	Feed	Col. #1 Discharge	Col. #2 Discharge	Col. #3 Discharge
	Jan. 31/84	6.5	-	-	-
2	Feb. 2/84	-	0.03	<0.005	0.01
6	Feb. 6/84	-	0.04	0.01	0.01
13	Feb. 13/84	-	0.08	0.01	0.01(0.02)*
20	Feb. 20/84	8.0	0.19	0.03	0.02
27	Feb. 27/84	-	0.17	0.03	0.02
34	Mar. 5/84	-	0.30	0.03	0.05
40	Mar. 11/84	6.0	-	-	-
41	Mar. 12/84	-	0.40	0.07	0.12
48	Mar. 19/84	-	0.50	0.05	0.04
51	**Mar. 22/84	7.0	-	-	-
52	Mar. 23/84	-	-	0.18	0.13
55	Mar. 26/84	-	0.60	0.35	0.19
60	Mar. 31/84	6.0	-	-	-
62	Apr. 2/84	-	0.70	0.06	0.09
69	Apr. 9/84	-	0.80	0.09	0.10
74	Apr. 14/84	6.9	-	-	-
76	Apr. 16/84	-	0.95	-	-
80	Apr. 20/84	-	-	-	0.20
83	Apr. 23/84	-	1.3	-	-
90	Apr. 30/84	-	1.0	-	-
92	May 2/84	-	1.5	0.50	0.20

- Notes: 1. average feed concentration - 6.7 Bq/L Ra-226 (diss.)
 2. () * total Ra-226
 3. ** composition of Barrels 16-25 (not included in average)
 4. -- division line between batches, first day of batch is date of feed sample of subsequent batch.

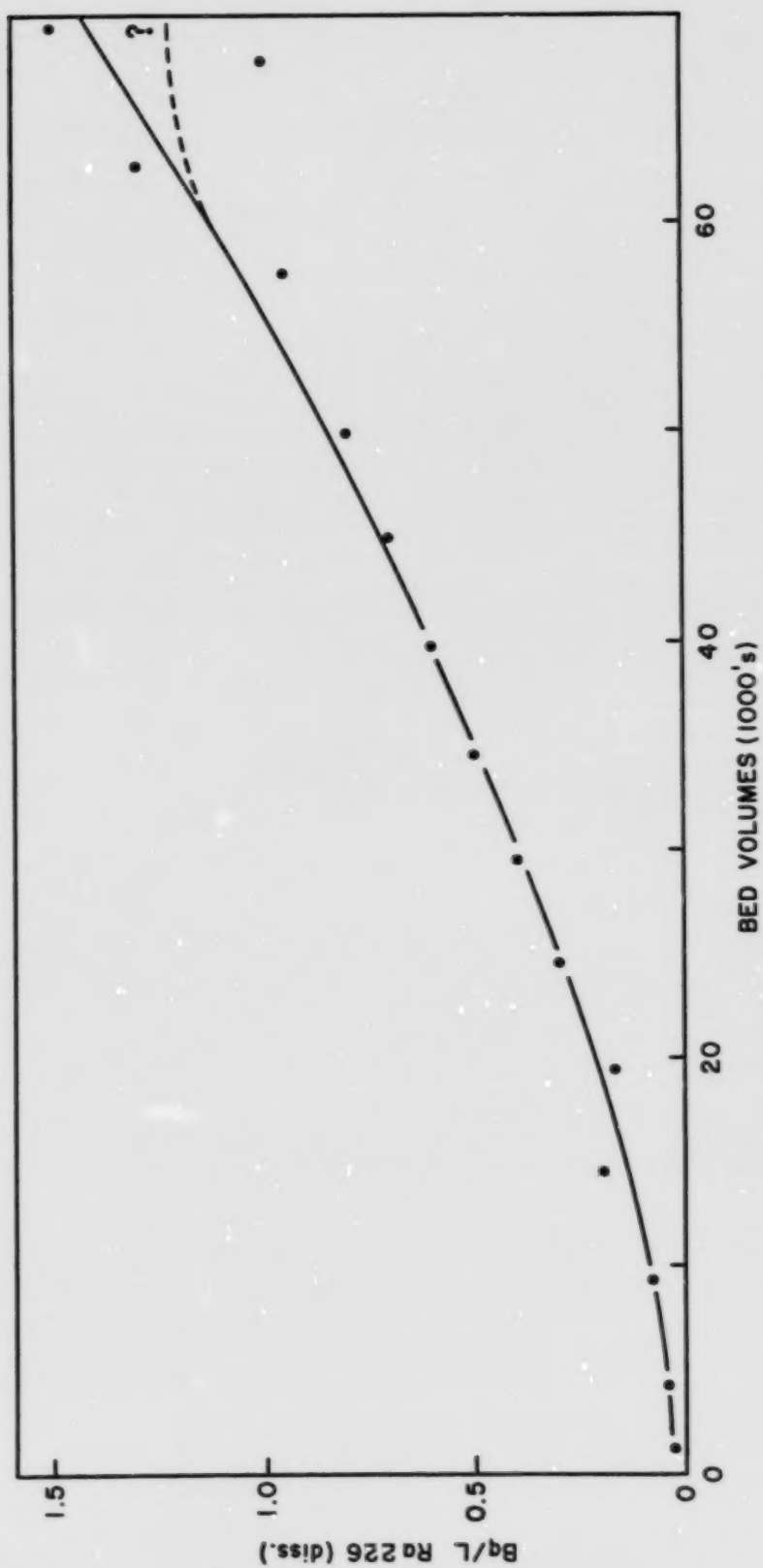


FIG. 3-4 PANEL COLUMN NO. 1 DISCHARGE ANALYSIS VS BED VOLUMES OF WATER TREATED

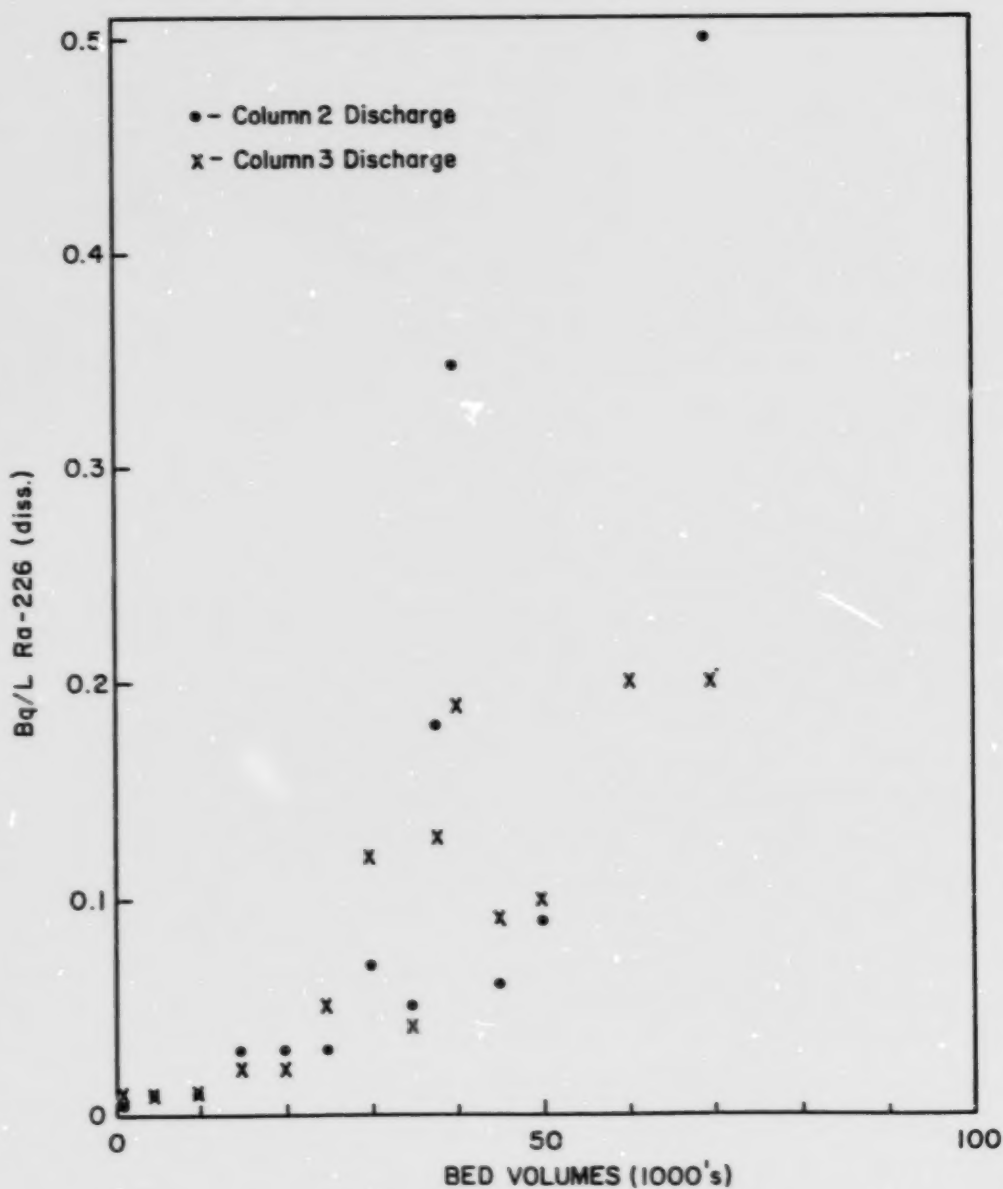


FIG.3-5 PANEL COLUMNS NO.2 AND NO.3 DISCHARGE RESULTS

Due to the scatter of data it is not possible to draw any conclusions from this graph although there appears to be a gradual increase of discharge values to 0.2 Bq/L Ra-226 (diss.)

The Key Lake test was operated continuously from February 17, 1984 to April 14, 1984 for a total operating time of 58 days which represented a total of 21,700 bed volumes of water being treated. The Ra-226 analyses for the Key Lake test are given in Table 3-8.

The average feed concentration of the bulk sample of Key Lake grinding water used in the test was 60.0 Bq/L Ra-226 (diss.) After 21,700 bed volumes of water the discharge of Column No. 1 increased from 0.55 Bq/L Ra-226 (diss.) to 3.0 Bq/L Ra-226 (diss.) A graphical presentation of these results is shown in Figure 3-6.

As shown in Figure 3-7 the discharge of Columns No. 2 and No. 3 were not significantly different with a level of 0.2 Bq/L Ra-226 (diss) being obtained in Columns No. 2 and No. 3 after treating 21,700 bed volumes of water. The higher radium levels of Column No. 2 and Column No. 3 discharges in the first 5,000 bed volumes are an indication that the calcium exchange phase at the start of treatment with fresh resin may interfere with radium removal when treating contaminated water containing low levels of calcium.

For comparison purposes the discharge analysis of Column No. 1 for both tests was plotted in Figure 3-8 as a percentage of the column feed analysis in terms of bed volumes of water treated. It appears from this graph that both columns performed in a similar way in terms of radium removal efficiency considering that the results appear to be at the low end of the breakthrough curve for the resin. One or two data points could be interpreted to give an elongated "S" curve although there is insufficient data for this to be definitive.

Since the volume of water available for treatment in both tests was only sufficient to produce results which are thought to be at the

TABLE 3-8

KEY LAKE TEST-DISSOLVED RADIUM-226 ANALYSES (Bq/L)

Days of Operations	Date Sampled	Feed	Col. #1 Discharge	Col. #2 Discharge	Col. #3 Discharge
1	Feb. 17/84	-	(0.45)*	-	-
4	Feb. 20/84	65	0.55	0.35	0.30
11	Feb. 27/84	-	0.55	0.30	0.35(0.70)*
12	Feb. 28/84	55	-	-	-
18	Mar. 5/84	-	0.50	0.13	0.14
23	Mar. 10/84	50	-	-	-
25	Mar. 12/84	-	0.80	0.08	0.10
32	Mar. 19/84	-	1.0	0.09	0.08
33	**Mar. 20/84	65	-	-	-
36	Mar. 23/84	65	-	0.35	0.15
39	Mar. 26/84	-	2.0	0.20	0.18
46	Apr. 2/84	-	2.5	0.10	0.12
47	Apr. 3/84	65	-	-	-
53	Apr. 9/84	-	2.8	0.2	0.18
58	Apr. 14/84	-	3.0	-	0.19

- Notes: 1. average feed concentration - 60.0 Bq/L Ra-226 (diss)
 2. ()* total Ra-226
 3. ** composite of Barrels 16-25 (not included in average)
 4. -- division line between batches, first day of batch is date of feed sample of subsequent batch.

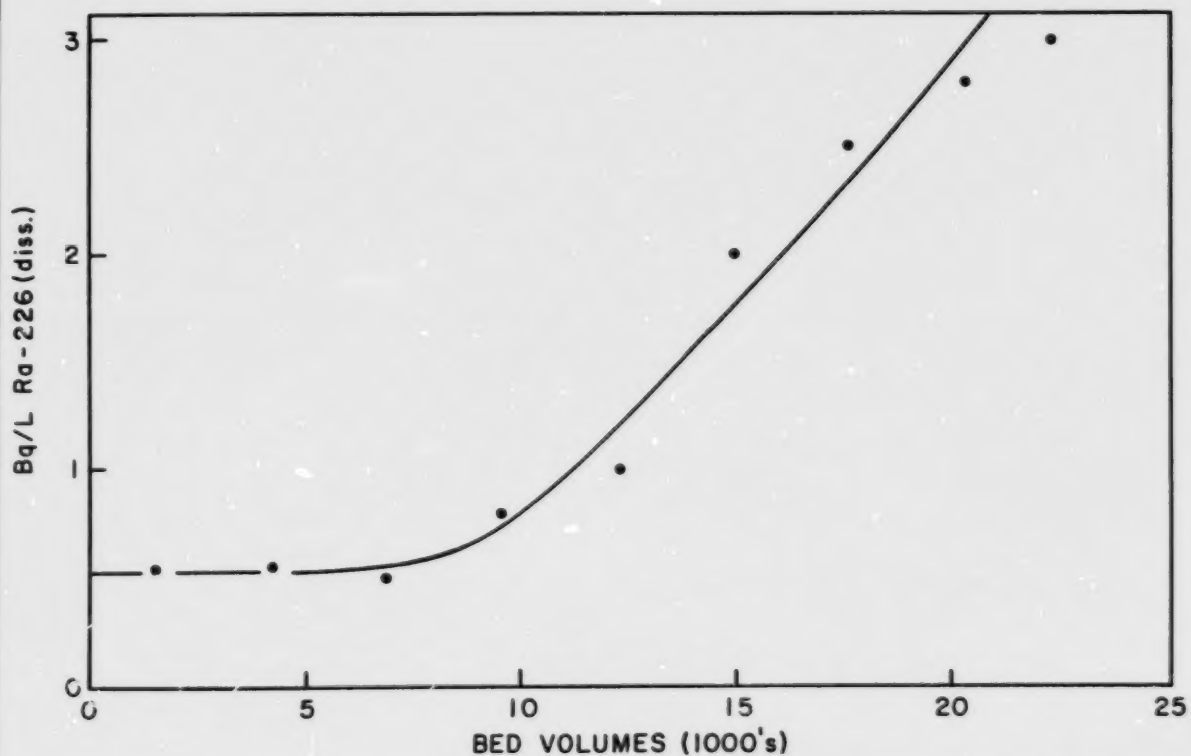


FIG.3-6 KEY LAKE COLUMN NO.1 DISCHARGE ANALYSIS VS BED VOLUMES OF WATER TREATED

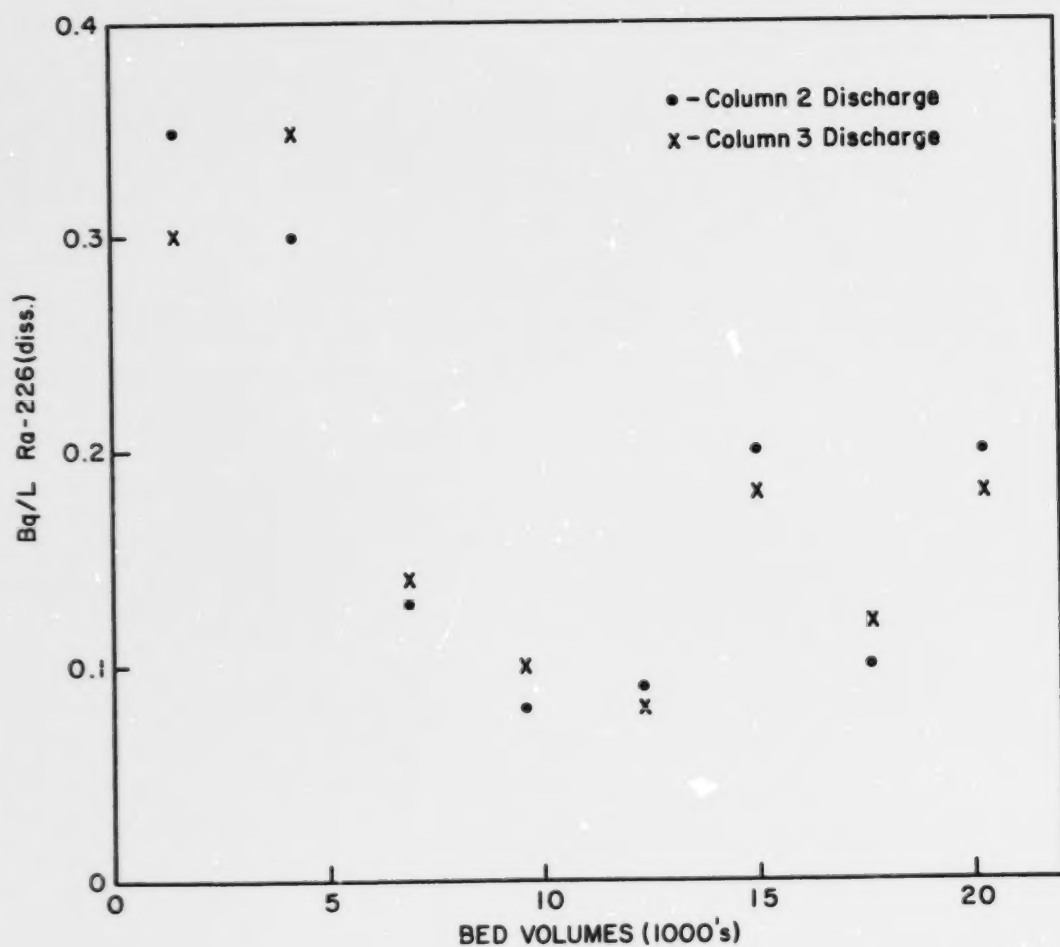


FIG.3-7 KEY LAKE COLUMNS NO.2 AND NO.3 DISCHARGE RESULTS

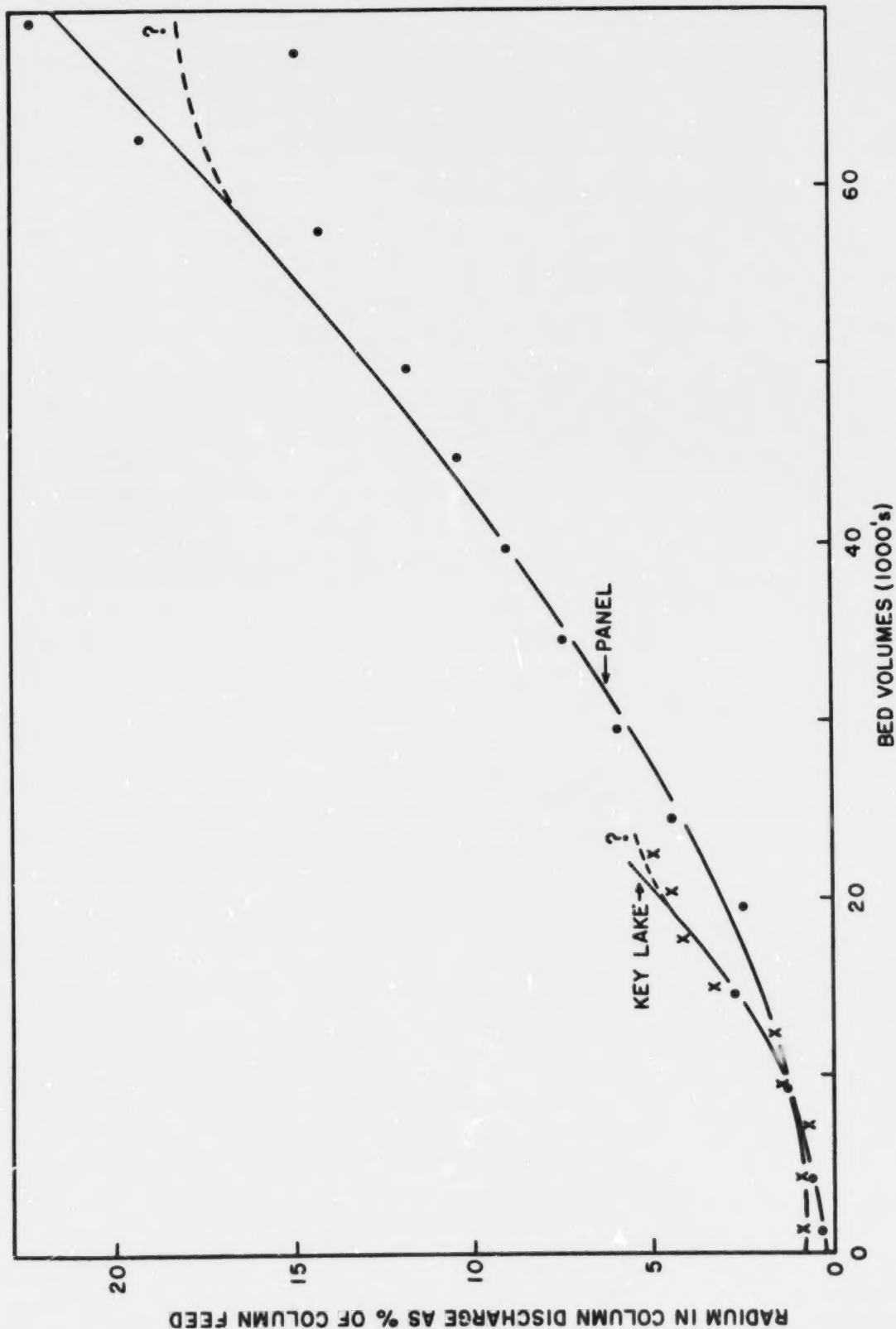


FIG.3-8 COLUMN NO.1 DISCHARGE RADIUM ANALYSES AS PERCENT OF FEED

low end of the breakthrough curve no attempt was made at extrapolating this graph to determine the number of bed volumes required to achieve breakthrough or saturation of the resin in Column No. 1. However it does appear from these results that breakthrough would occur with a much lower number of bed volumes for the Key Lake water due to its higher feed concentration of radium.

From the results given above it is apparent that breakthrough, or saturation of the resin, was not achieved in either test after treatment of the available bulk sample of water. However a good approximation of the maximum loading capacity of the resin was possible by extrapolating available data as described in Section 3.3.5 of this report.

The effect of flowrate on radium removal efficiency was tested in the Panel columns by increasing the specific flowrate through the columns from the normal test conditions of $16.6 \text{ m}^3/\text{h}/\text{m}^2$ to 28, 38 and $49 \text{ m}^3/\text{h}/\text{m}^2$ and allowing the system to operate at the specified flowrate for twenty-four hours prior to sampling the column discharges. The radium levels in the discharge from each columns are provided in Table 3-9 for the specific flowrates tested. There was no noticeable difference in the radium content of the column discharges as the flowrate was increased from $16.6 \text{ m}^3/\text{h}/\text{m}^2$ to $49 \text{ m}^3/\text{h}/\text{m}^2$. This indicated that the radium removal efficiency was not affected by an increase in flow under the conditions used in the tests. It can be assumed therefore that the resin columns could be operated efficiently at 100% bed expansion ($33 \text{ m}^3/\text{h}/\text{m}^2$) when treating contaminated water similar to the Panel tailings decant water.

A more complete analysis of the final discharge (Column No. 3) sampled at test completion for each set is given in Table 3-10 for both the Panel and Key Lake tests. The feed analysis of both feed samples are reproduced in this table for ease of comparison.

TABLE 3-9

EFFECT OF SPECIFIC FLOWRATE ON RADIUM REMOVAL

<u>Day of Operation</u>	<u>Specific Flowrate (m³/h/m²)</u>	<u>Bq/L Ra-226 (diss.)</u>		
		<u>Col. #1 Discharge</u>	<u>Col. #2 Discharge</u>	<u>Col. #3 Discharge</u>
69	16.6	0.8	0.09	0.10
70	49	0.9	0.07	0.07
71	38	0.8	0.20	0.05
72	28	0.85	0.08	0.07

TABLE 3-10

COLUMN No. 3 FINAL DISCHARGE ANALYSES (at test completion)

Element	Panel Mine Tailings Decant Water		Key Lake Grinding Circuit Water	
Bq/L	Feed(1)	Discharge(2)	Feed(1)	Discharge(2)
Gross α	14	9.0	90	33
Gross β	17	12.4	40	15.5
Pb-210 (total)	0.25	0.9	1.3	0.4
Pb-210 (diss)	0.15	-	0.15	0.15
Po-210 (total)	<0.005	-	1.1	-
Po-210 (diss)	-	-	-	0.40
Ra-226 (total)	6.7	0.20	60	0.25
Ra-226 (diss)	6.7	0.20	60	0.19
Th-227 (total)	0.1	-	0.02	-
Th-227 (diss)	0.07	-	0.04	-
Th-228 (total)	0.09	0.2	0.35	<0.02
Th-228 (diss)	0.05	-	0.06	-
Th-230 (total)	0.16	0.17	1.2	0.07
Th-230 (diss)	0.04	-	0.35	-
Th-232 (total)	0.3	<0.02	0.3	<0.02
Th-232 (diss)	0.01	-	0.08	-
<u>mg/L</u>				
U (total)	0.19	0.21	2.3	1.1
U (diss)	0.17	-	1.8	-
B	0.25	0.33	0.3	0.35
P	<0.05	<0.05	0.1	0.06
Ag	<0.001	<0.001	<0.001	<0.001
Al	0.13	1.3	0.076	0.059
Ba	0.046	0.087	0.038	0.12
Be	<0.001	<0.001	<0.001	<0.001
Ca	400	335	38	61
Cd	<0.001	<0.001	0.001	<0.001
Co	0.013	0.015	0.024	0.022
Cr	0.010	0.002	0.008	0.005
Cu	0.084	0.077	0.017	0.037
Fe	0.50	0.076	0.35	0.23
K	85	149	20	20
Mg	13	19	36	35
Mn	0.28	0.32	0.18	0.19
Mo	<0.005	<0.005	0.43	0.39
Na	58	91	11	12
Ni	0.056	0.093	13	11
Pb	<0.005	<0.005	<0.005	0.008
Ti	<0.001	<0.001	<0.001	<0.001
V	0.01	<0.01	0.02	0.01
W	<0.005	<0.005	<0.005	<0.005
Zn	0.11	0.79	0.006	0.17
As	0.003	-	1.0	0.29
TSS	2	2	4	4
TDS	2,500	2,500	578	550
pH	4.8		5.1	

- (1) feed sample taken at start of test (ie. representative of first batch).
 (2) discharge sample taken as one grab sample at test completion.

From these results it is apparent that the resin is efficient in removing radium from contaminated uranium mining effluents. Some of the results indicate that other radionuclides are also removed although the levels of these other radionuclides in the water treated were much lower than the radium level.

The Key Lake results indicate that the resin may have some capacity for removing arsenic from contaminated water but the decrease in arsenic from 1.0 mg/L As to 0.29 mg/L As may have been due to the formation of a gelatinous-type precipitate in Column No. 1 during treatment of the Key Lake water (see Plate No. 3). Approximately 300 mg of this material was removed from the column and analysed for various elements as listed in Table 3-11. These assays indicated that the material was likely an iron arsenate precipitate co-precipitated with fine clay and ore particles. The flocculated appearance of the material was indicative of the origin of the water sample which was neutral thickener overflow. The presence of this material at the top of No. 1 Column for the Key Lake test did not affect the operation of the upflow column.

A small amount of an iron-type precipitate was also noticed above the bed in Column No. 1 for the Panel test (see Plate No. 4) but the amount of this precipitate was considered insignificant compared to the volume of water treated.

The increase in zinc concentration from 0.11 mg/L Zn to 0.79 mg/L Zn for the Panel test and an increase from 0.09 mg/L Zn to 0.17 mg/L Zn for the Key Lake test was possibly due to the use of brass fittings in the test apparatus. The slightly acidic nature of the water (pH 5) may have resulted in some dissolution of the zinc contained in the brass.

3.3.2 Water and Radium Balances

A water and radium balance for the Panel test is presented in

TABLE 3-11ANALYSES OF PRECIPITATE IN KEY LAKE COLUMN NO. 1

<u>Element</u>	<u>Analysis (µg/g)</u>
B	96
P	880
Ag	5
Al	26,000
As	45,000
Ba	490
Be	30
Ca	1,400
Cd	320
Co	96
Cr	330
Cu	5,000
Fe	105,000
K	3,300
Mg	5,700
Mn	39
Mo	4,900
Na	1,400
Ni	5,100
Pb	90
Ti	120
V	500
W	570
Zn	1,100
U	13,500
Ra-226	13 (Bq/g)

Figure 3-9 for the total operating period in terms of kilograms of water treated and becquerels of radium present in the various streams. This balance is based on a feed analysis of 6.7 Bq/L Ra-226 (diss.) and a total bulk sample of 4,860 kg of water. Balances on an individual basis for the five batches of Panel water treated are given in Appendix C. The number of significant figures given in these results are for calculation purposes only.

The Key Lake balance, presented in Figure 3-10, is based on a feed concentration of 60.0 Bq/L Ra-226 (diss.) and a total bulk sample of 4,589 kg of water. A total of 21,700 bed volumes of water were treated in the Key Lake set of columns. The balances for the five individual batches of Key Lake water treated are presented in Appendix D.

A summary of the radium removal efficiency of Column No. 1 versus increasing volumes of water being treated for the Panel and Key Lake tests is provided in Tables 3-12 and 3-13 respectively. There was a continual drop in efficiency for each batch of water treated which caused a corresponding drop in the cumulative removal efficiency of the resin. For the Panel test the radium removal efficiency dropped to 81.3% after treatment of 69,350 bed volumes of water while the radium removal efficiency for the Key Lake test was down to 95.4% after treatment of 21,700 bed volumes of water.

The batch and cumulative radium removal efficiencies of Column No. 1 for both types of water are presented in Figures 3-11 and 3-12 respectively. From these graphs it is evident that there is a continuing drop in efficiency which is directly related to the chemistry of the water treated in terms of the number of bed volumes passed through the resin. Although the radium removal efficiency of Column No. 1 for the Key Lake water appears to follow the Panel test on a cumulative basis it is apparent that the efficiency of Key Lake Column No. 1 is decreasing more rapidly in terms of bed volumes of water treated which is likely due to the higher radium concentration in the feed water being treated.

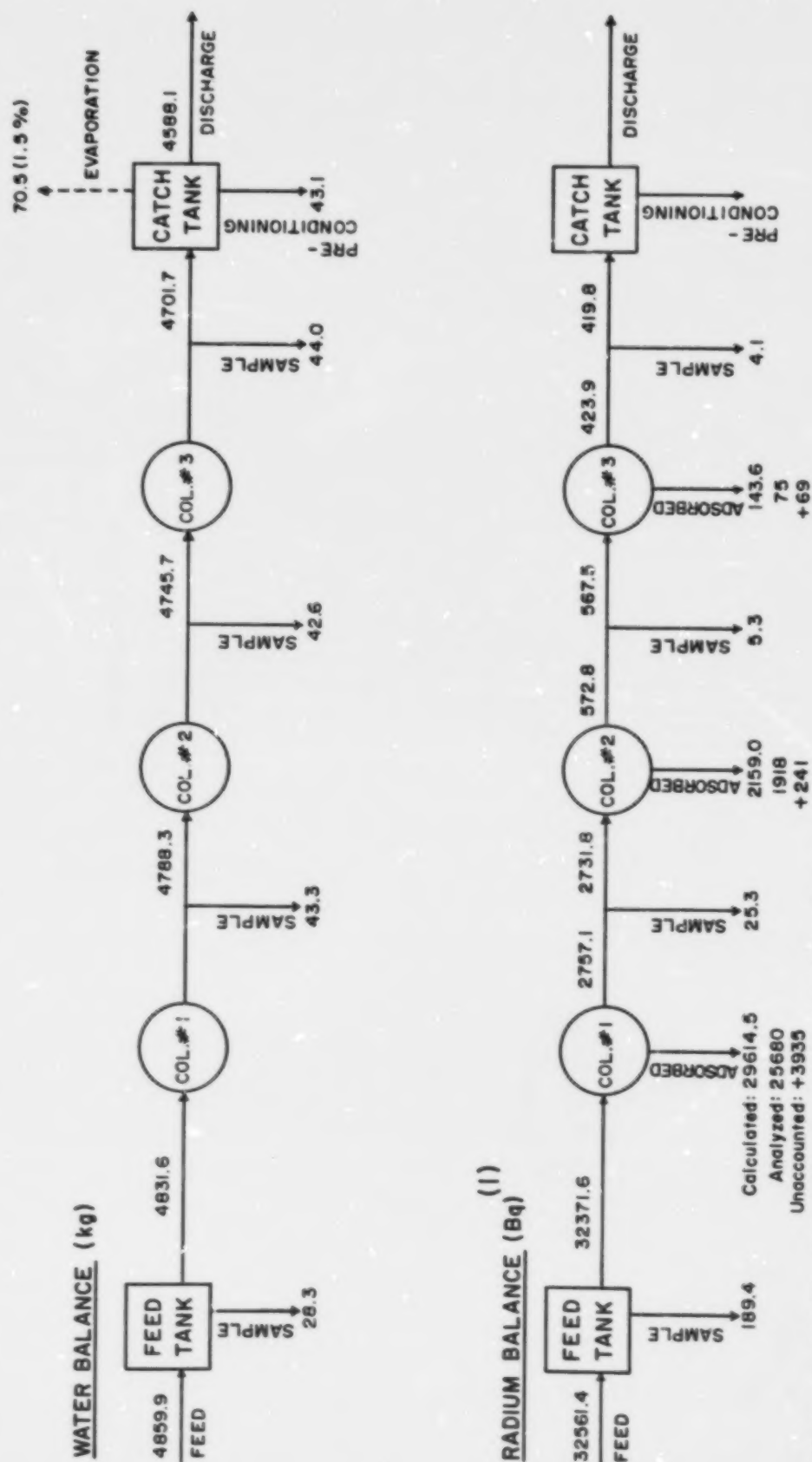
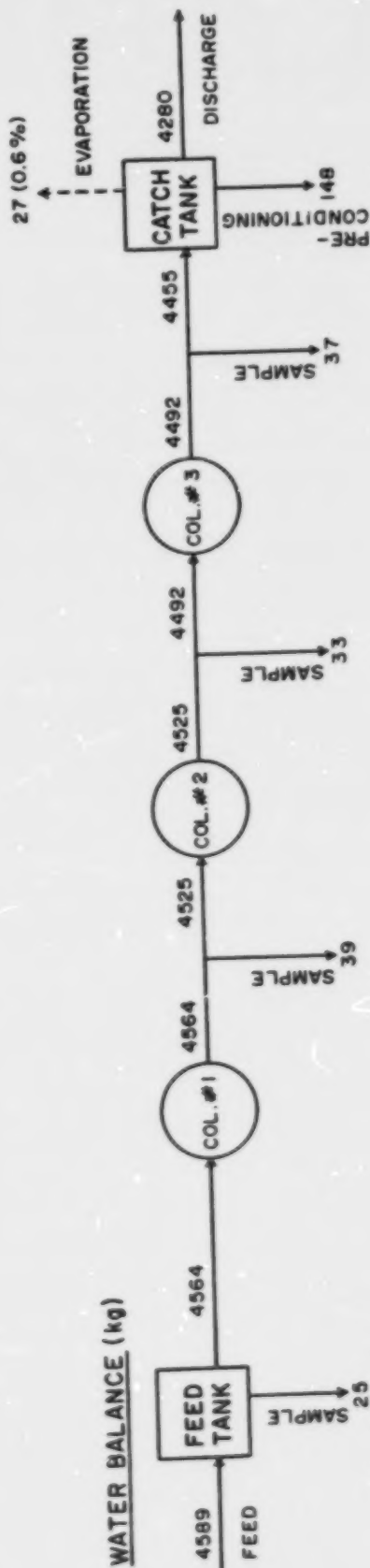


FIG. 3-9 PANEL WATER AND RADIUM BALANCE

(1) Values given in radium balance are carried to 6 significant figures for calculation purposes only.

WATER BALANCE (kg)



RADIUM BALANCE (Bq)

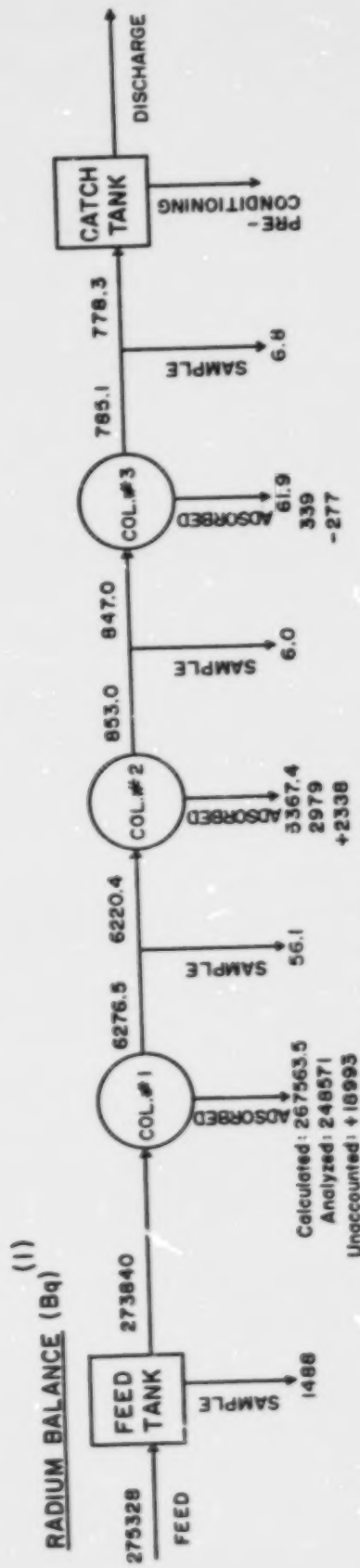


FIG. 3-10 KEY LAKE WATER AND RADIUM BALANCE

(1) Values given in radium balances are carried to 7 significant figures for calculation purposes only.

TABLE 3-12

PANEL TEST-SUMMARY OF COLUMN NO. 1 RESULTS

Batch No.	kg Water to No. 1 Column Bed Volumes Treated		(1) Bq Ra-226 in Feed		(2) Bq Ra-226 Adsorbed		(3) Ra Removal Efficiency(%)	
	Batch	Cumulative	Batch	Cumulative	Batch	Cumulative	Batch	Cumulative
1	933.6	933.6	13,400	13,400	6,255	6,190	99.0	99.0
2	1,040.6	1,974.2	14,936	28,336	6,972	6,712	96.3	97.5
3	989.1	2,963.3	14,197	42,533	6,627	6,132	92.5	95.9
4	885.0	3,848.3	12,703	55,236	5,930	5,222	88.1	94.1
5	983.3	4,831.6	14,114	69,350	6,588	5,359	81.3	91.5

NOTES: 1. Bed volume based on wet settled resin bed height during operating period.

2. Based on average feed concentration of 6.7 Bq/L Ra-226 (diss).

3. Based on average analysis of No. 1 Column discharge for each batch treated.

TABLE 3-13
KEY LAKE TEST-SUMMARY OF COLUMN NO. 1 RESULTS

Batch kg Water to No. 1 Column Bed Volumes Treated	(1)		(2)		(3)	
No.	Batch	Cumulative	Batch	Cumulative	Batch	Cumulative
1	848.1	848.1	4,030	4,030	50,886	50,886
2	915.6	1,763.7	4,351	8,381	54,936	105,822
3	1,020.9	2,784.6	4,851	13,232	61,254	167,076
4	916.1	3,700.7	4,353	17,585	54,966	222,042
5	863.3	4,564.0	4,102	21,687	51,798	273,840
					50,420	50,430
					54,460	104,880
					60,254	165,134
					53,024	218,158
					49,407	267,565
					99.1	99.1
					99.1	99.1
					98.4	98.8
					96.5	98.3
					95.4	97.7

- NOTES: 1. Bed volume based on wet settled resin bed height during operating period.
2. Based on average feed concentration of 60.0 Bq/L Ra-226 (diss.).
3. Based on average analysis of No. 1 Column discharge for each batch treated.

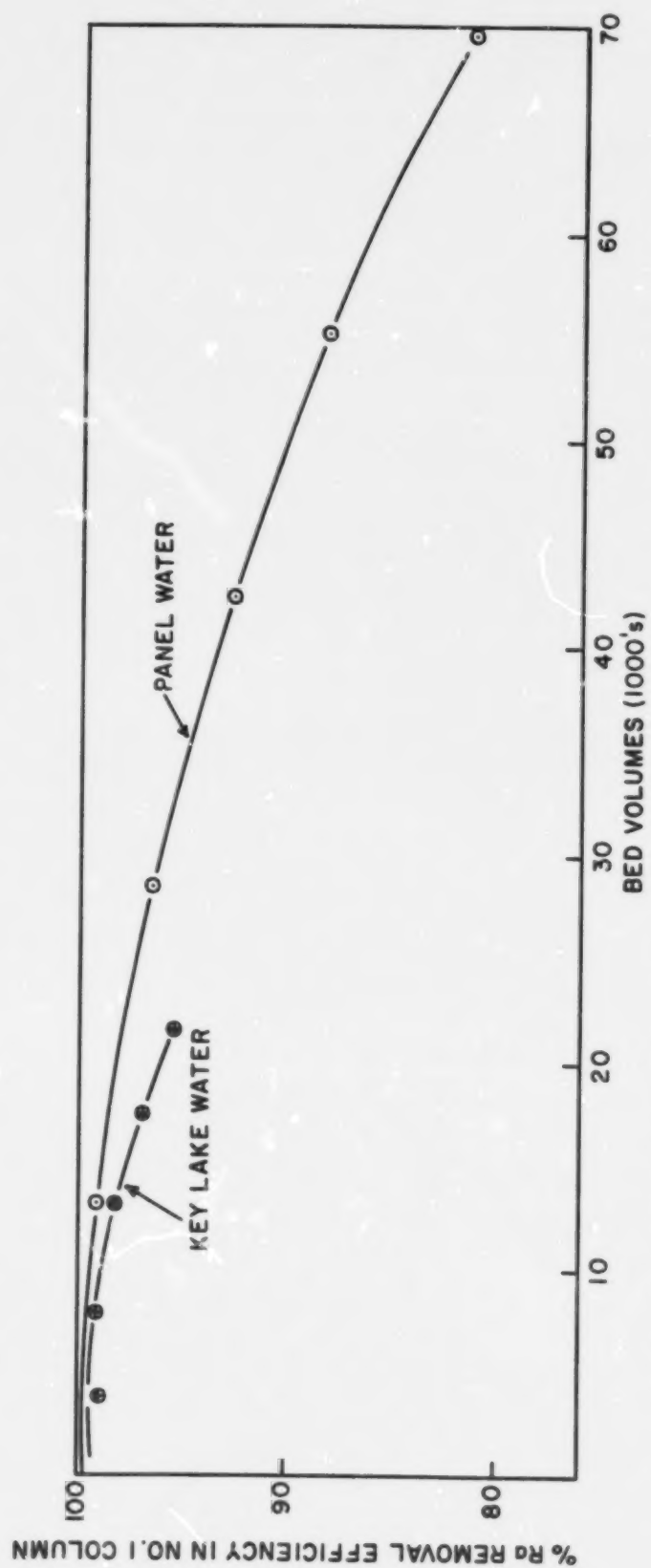


FIG.3-11 BATCH RADIUM REMOVAL EFFICIENCY IN NO.1 COLUMN VS BED VOLUMES OF WATER TREATED

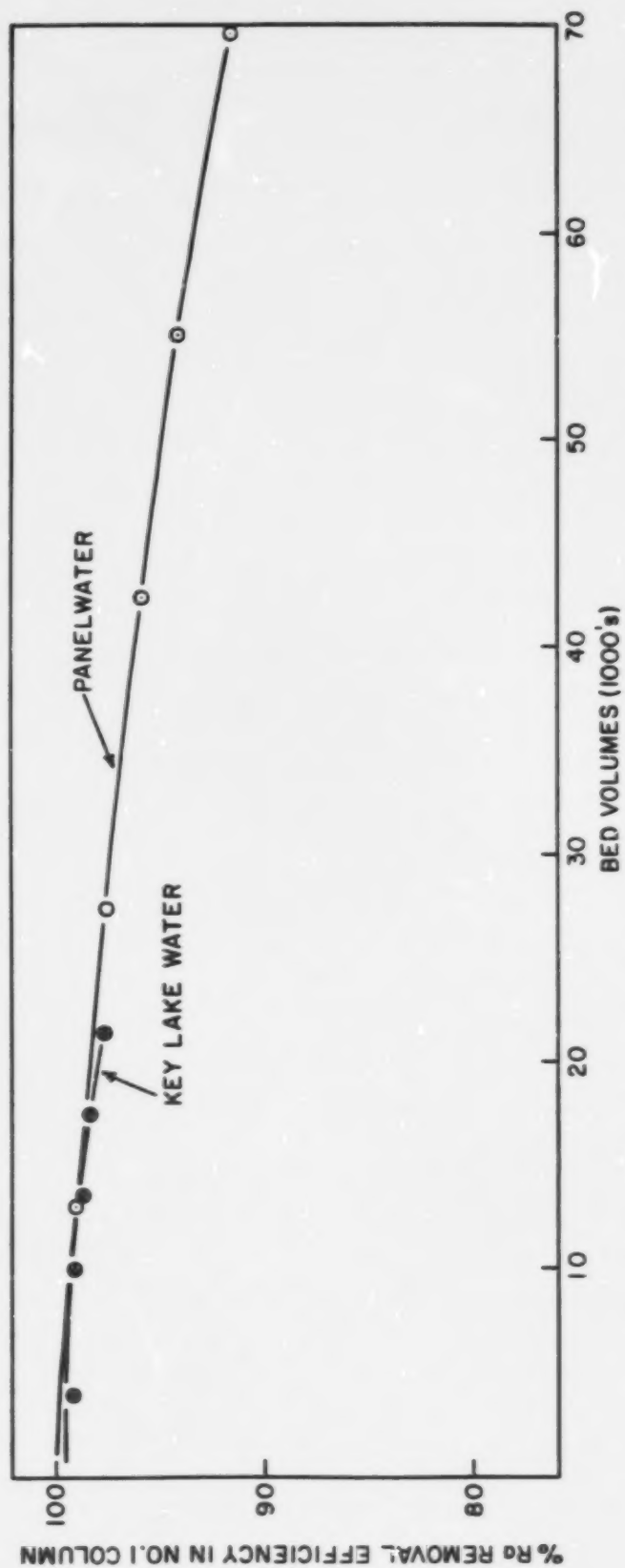


FIG.3-12 CUMULATIVE RADIUM REMOVAL EFFICIENCY IN NO.1 COLUMN VS BED VOLUMES OF WATER TREATED

The results of Column No. 2 and No. 3 for both types of water are summarized in Table 3-14 for the total operating period. The overall radium removal efficiency of Column No. 2 for the total operating period was calculated as 79% and 86% for the Panel and Key Lake test respectively. Column No. 3 efficiencies were 25% and 7% respectively. It should be noted that these results are presented for completeness only since radium balances can only be considered as approximate due to analytical errors involved in sampling and analysis of radionuclides. This fact is evident when comparing calculated and analysed values.

Using the calculated radium adsorption values for Column No. 1 in Tables 3-12 and 3-13 the radium loading on the resin in Column No. 1 was calculated based on the weight of resin in No. 1 Column for the Panel and Key Lake test (see Table 3-5). This calculation indicates that the Ra-226 loading in No. 1 Column at test completion for the Panel test was 1384 Bq/g and for the Key Lake test, 4372 Bq/g. These values compared favourably with the assay values of the resin given in Section 3.3.3.

3.3.3 Resin Analyses

At the completion of the test program the columns were drained of water and the resin removed for analysis. The radium analysis of the resin in each column along with the dry weight of resin removed (based on a wet settled resin weight measurement and a resin moisture of 72%) are presented in Table 3-15 for both the Panel and Key Lake tests.

The resin in No. 1 Column for the Key Lake test was separated into three different sections since there appeared to be segregation of the resin in the column due to a limited bed expansion (29%) at the flowrate used in the test. Consequently it was anticipated that the resin in the bottom third of the column would be approaching saturation more quickly than the upper two-thirds of the column. By analysing the bottom third separately it would therefore be possible to collect a resin sample which would be approaching

TABLE 3-14

COLUMN NO. 2 RESULTS

	<u>Panel</u>	<u>Key Lake</u>
Radium to column (Bq)	2,732	6,220
Radium adsorbed in column (Bq)	2,159	5,367
Cummulative radium adsorption efficiency (%)	79	86
Weight of resin in column (g)	21.8	62.1
Radium loading on resin (Bq/g) - calculated	99	86
- analysed	88	48

COLUMN No. 3 RESULTS

Radium to column (Bq)	568	847
Radium adsorbed in column (Bq)	144	62
Cumulative radium adsorption efficiency (%)	25	7
Weight of resin in column (g)	20.4	62.8
Radium loading on resin (Bq/g) - calculated	7.1	1.0
- analysed	3.7	5.4

TABLE 3-15

RESIN RADIUM-226 ANALYSESPANEL

	<u>Radium (Bq/g)</u>	<u>Dry Weight of Resin (g)</u>	<u>Total Ra-226⁽¹⁾ (Bq)</u>	<u>Total Ra-226 from Water Balance (Bq)</u>
Col. No. 1	1,200	21.4	25,680	29,615
Col. No. 2	88	21.8	1,918	2,159
Col. No. 3	3.7	20.4	75	144

KEY LAKE

	<u>Radium (Bq/g)</u>	<u>Dry Weight of Resin (g)</u>	<u>Total Ra-226⁽¹⁾ (Bq)</u>	<u>Total Ra-226 from Water Balance (Bq)</u>
Col. No. 1				
- average	4,064	61.16	248,571	267,564
- top third	1,800	21.18	38,124	
- middle third	3,900	18.17	70,863	
- bottom third	6,400	21.81	139,584	
Col. No. 2	48	62.06	2,979	5,367
Col. No. 3	5.4	62.75	339	62

(1) significant figures given are for calculation purposes only.

saturation in terms of radium loading. The results in Table 3-15 confirmed this since the resin in the bottom third of Key Lake No. 1 Column assayed 6400 Bq/g Ra-226 while the top third portion of the column only assayed 1800 Bq/g Ra-226. A value of 6400 Bq/g Ra-226 appeared to be close to the ultimate loading capacity of the resin determined by extrapolation of data in Section 3.3.5 of this report.

The total radium adsorbed in No. 1 Column, as determined by analysis of the resin, is in fair agreement with the values calculated from the water balances given in Tables 3-12 and 3-13 and reproduced in Table 3-15.

A more complete resin analysis is presented in Table 3-16 for the resin in Column No. 1 for both the Panel test and the Key Lake test. The analyses of the as-received resin is reproduced for ease of comparison. These results indicate that the resin adsorbs aluminium, barium, calcium, iron and magnesium. Nickel and arsenic are also adsorbed to a certain extent but this is relatively insignificant when comparing the feed and discharge water analyses for the Key Lake test (see Table 3-10). The exchange of calcium ions for sodium ions on the resin is evident from a comparison of sodium and calcium analyses of loaded and fresh resin. The high calcium loading of the resin from the Panel test is an indication that treatment of water high in calcium ions could lead to poor loading efficiencies. The presence of Bi-214 and Pb-214 in the Key Lake resin are due to the natural decay of the radium present in the resin.

The contaminated resin produced during the testwork was retained for check analysis prior to returning it to Dow Chemical Canada Inc., Sarnia, Ont. as part of the original agreement for obtaining the resin for laboratory investigations.

3.3.4 Radiation Measurements

Gamma radiation levels at Column No. 1 of the Panel and Key Lake

TABLE 3-16

LOADED RESIN ANALYSES ($\mu\text{g/g}$ dry basis)

<u>Element</u>	<u>New Resin</u>	<u>Panel No. 1 Column</u>	<u>Key Lake No. 1 Column</u>
B	< 10	10	10
P	< 40	40	40
Al	28	560	19
Ba	1,800	2,700	2,100
Be	< 1	< 1	< 1
Ca	300	55,700	33,500
Cd	< 1	< 1	< 1
Co	5	5	14
Cr	300	270	410
Cu	6	36	23
Fe	590	1,400	800
Mg	20	1,600	13,800
Mn	26	42	95
Mo	< 4	< 4	92
Na	60,000	640	260
Ni	200	100	5,800
Pb	< 4	6	< 4
Ti	< 1	< 1	< 1
V	< 10	< 10	10
W	< 4	< 4	10
Zn	40	62	59
As	< 1	-	360
U	-(1)	8	359
Ra-226 (Bq/g)	1	1,200	4,064
Pb-214 (Bq/g)	-	-	1,920(2)
Bi-214 (Bq/g)	-	-	1,920(2)
Pb-210 (Bq/g)	-	-	< 10(2)
Th-234 (Bq/g)	-	-	< 10(2)
Th-232 (Bq/g)	-	-	< 10(2)

(1) dash signifies element not analysed.

(2) assay of other radionuclides on Key Lake resin accomplished 4 months after shutdown of column by gamma spectroscopy.

sets were taken throughout the operating period of the columns. These measurements were taken at the surface of the column at various heights of Column No. 1 using a Berthold meter (model LB 1200). The gamma readings obtained are listed in Tables 3-17 and 3-18.

It can be seen from these results that there was a gradual increase in radiation levels in Column No. 1 with increasing bed volumes of water treated. This is a direct effect of radium loading on the resin as evident from the higher radiation levels noted in the Key Lake column which had a higher radium content compared to the Panel column. This is also evident from the much lower readings for Columns No. 2 and No. 3 in both sets.

From these gamma readings it appeared that there was some segregation of the resin in the lower section of the columns since the level of radiation at the bottom of Column No. 1 was higher than the top of the columns. The increase and stabilization of the radiation readings at approximately 210 imp/min at the bottom of No. 1 Column for the Key Lake test in the latter stages of operation indicated that the resin in the bottom of this column was likely saturated with radium. This levelling-off of radiation is depicted in Figure 3-13 where the radiation levels at various heights of Column No. 1 are plotted against operating time for the Key Lake test.

An increase in radiation was observed when the Key Lake columns were left standing for a period of time after the test was completed. In anticipation of continuing the test program the Key Lake columns had been left intact once treatment of the bulk sample of water was completed. By the time the decision was made to not extend the test, nineteen days later, the radiation levels of the settled resin had increased twenty-fold from the readings observed during the operation of the column (Table 3-18, May 3 readings). This increase was due to the

TABLE 3-17

PANEL COLUMN NO.1 GAMMA RADIATION SURVEYS (imp/min)

<u>Date</u>	<u>Height Above Bottom of Bed</u>			
	<u>8 cm</u>	<u>25 cm</u>	<u>55 cm</u>	<u>73 cm</u>
February 23	35-45		35-45	35-45
March 13	80-85		55-60	55-60
March 19	80-85		55	55
March 21	85-90		55	55
March 23	85-95		55-60	55
March 26	85-90		50-55	50-55
March 28	85-95		50-60	45-55
March 30	85-95		50-55	40-45
April 2	90-100		50-55	40-50
April 6	95-110		50-65	40-50
April 9	85-95		55-65	50-60
April 11	60-80	55-65	40-55	35-45
April 13	90-110	75-90	55-65	45-55
April 16	100-110	80-90	60-70	50-60
April 20	90-110	75-85	50-60	45-55

- Notes: 1. Columns No. 2 and 3 gave readings of 35-45 imp/min from March 13 to March 30. Readings in April were 35-50 imp/min.
2. 3000 imp/min = 1 mR/h.
3. Background was approximately 40 imp/min.
4. Measurements were taken on column surface.

TABLE 3-18

KEY LAKE COLUMN NO. 1 GAMMA RADIATION SURVEYS (imp/min)

<u>Date</u>	<u>Height Above Bottom of Bed</u>			
	<u>2.5 cm</u>	<u>30 cm</u>	<u>60 cm</u>	<u>95 cm</u>
February 23	40-45	40-45	40-45	40-45
March 13	150-160	100	70-75	50-55
March 19	175-180	130	75-80	60-65
March 21	210-215	130-140	75-80	60-65
March 23	195-205	135-140	75-80	60-65
March 26	200-210	150-170	85-110	55-60
March 28	195-210	150-160	85-100	50-60
March 30	200-215	150-165	85-95	65-70
April 9	200-215	150-160	95-110	70-85
April 11	220-260	160-180	90-120	50-65
April 13	200-240	170-200	90-110	60-80
May 3	4,000-4,500	2,800-3,000	1,100-1,300	400-425

- Notes:
1. Column 2 was 45-55 imp/min from March 13 to March 30.
 2. Column 3 was 40-50 imp/min from March 13 to March 30.
 3. 3000 imp/min = 1 mR/h
 4. Background was approximately 40 imp/min.
 5. May 3 readings taken after column had been shutdown for 19 days.
 6. Measurements were taken on column surface.

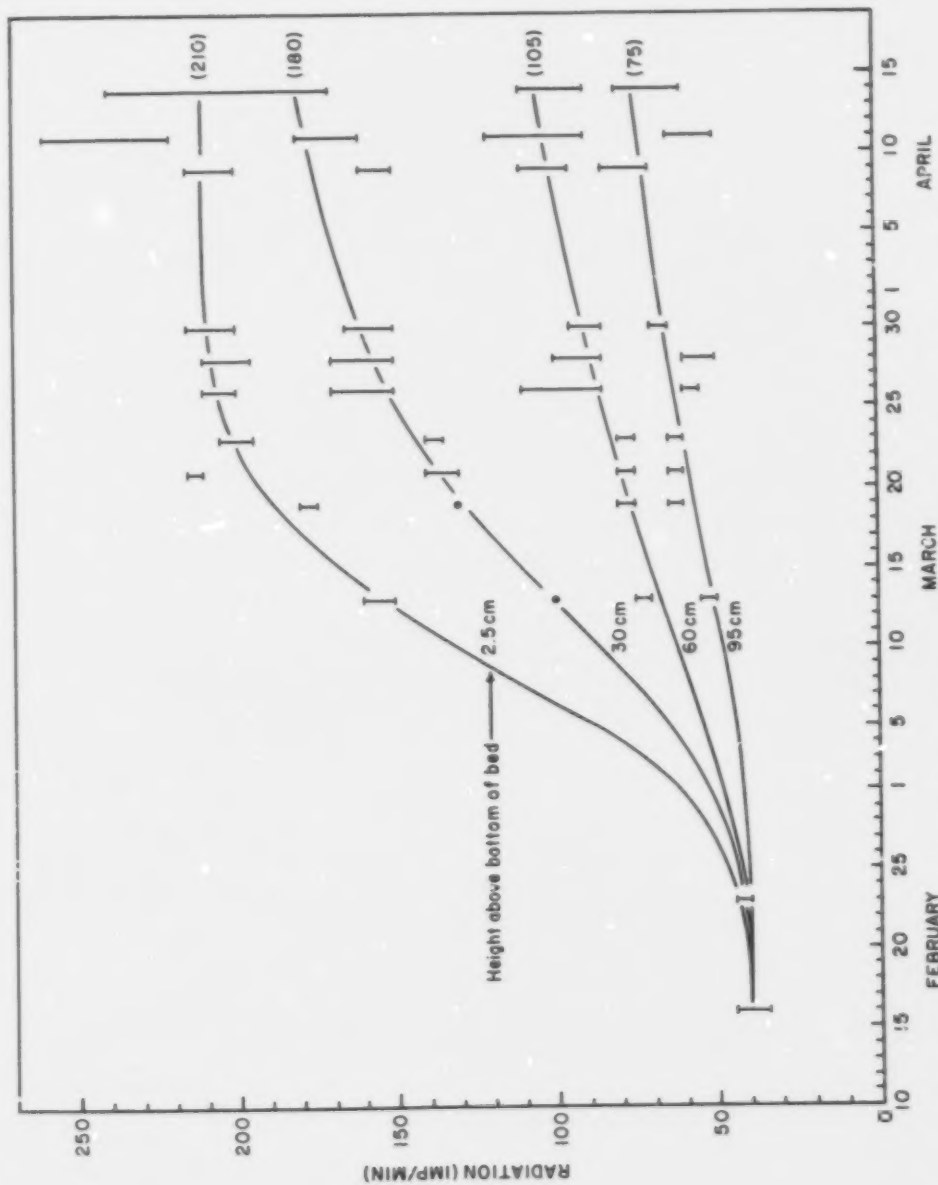


FIG. 3-13 KEY LAKE COLUMN NO.1 RADIATION SURVEYS (Background - 40 imp/min)

build-up of radon daughters which increased until they were in equilibrium with the complexed radium on the resin. With no flow of water occurring through the columns this build-up of daughter elements was not removed and hence radiation levels increased.

Radon measurements were taken in the vicinity of the test columns on February 20, 1984 during the operation of both the Panel and Key Lake columns. These measurements are given in Table 3-19 in terms of working levels. All levels were substantially lower than permissible levels with the highest value of 0.0243 WL found above the Key Lake water feed tank.

3.3.5 Resin Loading Capacity

Radium analysis of the resin at test completion (Table 3-15) indicated that the resin in the bottom third of No. 1 Column for the Key Lake test contained 6400 Bq/g Ra-226 and was approaching saturation based on radiation measurements of the column. By assuming that the resin at the bottom (height 0) of the Key Lake column would have been saturated with radium it was possible to extrapolate available data to estimate the maximum saturation point of the resin in terms of radium loading. The higher radium loading in the bottom of the column was attributed to partial segregation of the resin in the column (see Section 3.3.3).

Table 3-20 lists the radium loading of the resin for the three different sections of No. 1 Column for the Key Lake tests as well as radiation readings for various locations on the column. By plotting this data and using the radiation levels to indicate the shape of the curve Figure 3-14 shows that the maximum radium-loading capacity of the resin that could be anticipated is approximately 7000 Bq/g Ra-226 when treating Key Lake-type water.

A second method of extrapolating available data was used where the maximum radium loading on the resin was estimated using the radiation surveys listed in Table 3-18 for Key Lake Column No. 1

TABLE 3-19RADON MEASUREMENTS

<u>Location</u>	<u>WL</u>
General work area	0.0018
Key Lake feed tank (2.5 cm above water)	0.0243
Key Lake catch tank (2.5 cm above water)	0.0041
Panel feed tank (2.5 cm above water)	0.0043
Panel catch tank (2.5 cm above water)	0.0030

TABLE 3-20KEY LAKE COLUMN NO. 1RADIUM LOADING AND RADIATION MEASUREMENTS

<u>LOCATION</u>	<u>Ra-226 (Bq/g)</u>	<u>Radiation Reading⁽¹⁾ (imp/min)</u>
Top		420
Top 1/3	1,800	
2/3 Up		1,150
Middle 1/3	3,900	
1/3 Up		2,900
Bottom 1/3	6,400	
Bottom		3,875

Note: 1. Radiation measurements are an average of April 24 and May 3 readings of wet settled resin after the radiation level had increased and stabilized following the shutdown of the column.

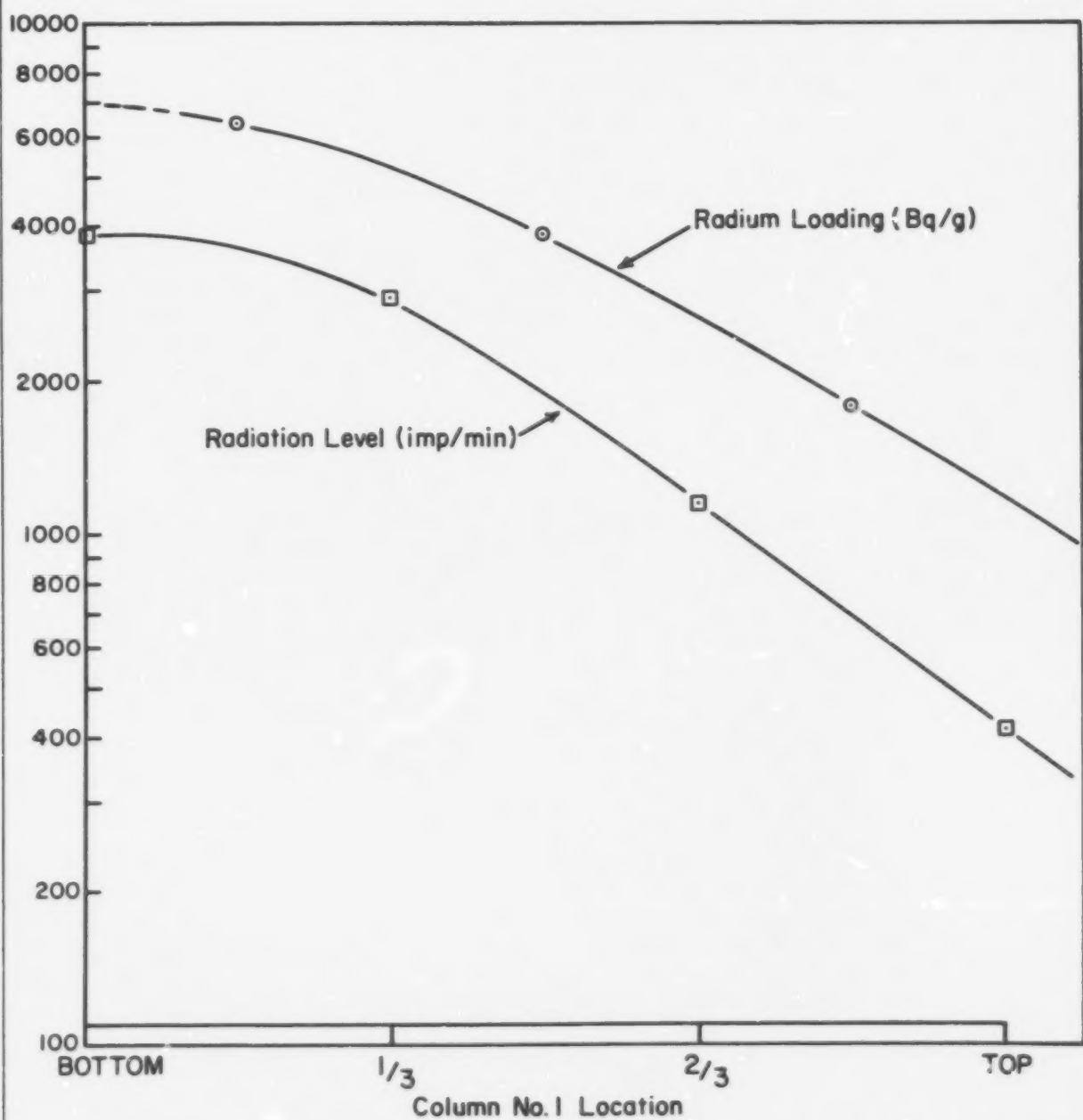


FIG.3-14 KEY LAKE COLUMN NO.1 RESIN RADIUM LOADING AND RADIATION MEASUREMENTS ON COLUMN SURFACE

along with radium mass balance data and assuming that the net radiation was proportional to the radium concentration in the resin.

Using extrapolated data from Figure 3-13 the net radiation values of the Key Lake column at test completion were plotted against column height in Figure 3-15. Integration of this curve provided an average net radiation value of 98.4 imp/min for Key Lake Column No. 1. From Figure 3-15 the maximum net radiation which would occur at the base of the column is 170 imp/min.

Assuming a direct relationship between radium loading and radiation levels it can therefore be stated that the resin in the No. 1 Column of the Key Lake test was only 57.9% loaded $((98.4/170) \times 100)$. At test completion Column No. 1 of the Key Lake test had adsorbed 267,565 Bq of radium (Table 3-13) after treating 21,687 bed volumes of Key Lake water. Therefore the maximum resin loading that could be expected would be 7,550 Bq/g Ra-226 $(267,565 \text{ Bq} / (61.2 \text{ g} \times 0.579))$. This second estimate compares favourably to the value of 7,000 Bq/g which was extrapolated from graphical data.

From these estimates a radium loading of 7,000 to 7,500 Bq/g Ra-226 of dry resin can therefore be anticipated when treating contaminated water similar to the Key Lake water treated in these tests. This radium loading is only an estimate of the ultimate loading capacity of the resin. The actual loading capacity of the resin would of course be dictated by the chemistry of the water being treated and the number of columns being operated in series with the controlling factor being the radium level in the last column discharge.

In this program it was not possible to determine what the radium loading in Column No. 1 would have been when the discharge of Column No. 3 reached 0.37 Bq/L Ra-226 (total). From the results presented in Tables 3-7 and 3-8 it did appear however

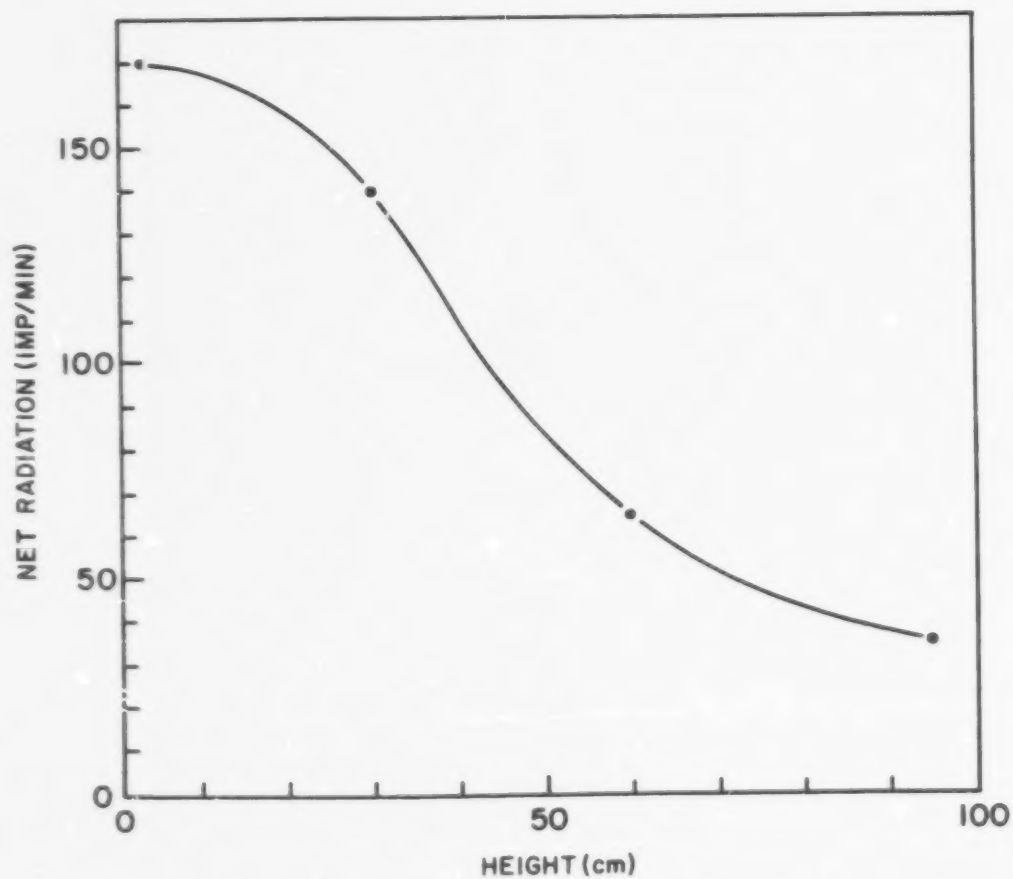


FIG. 3-15 KEY LAKE COLUMN NO.1 NET RADIATION VALUES
AT TEST COMPLETION

that there was a possibility of reaching a level of 0.37 Bq/L Ra-226 in No. 3 Column discharge for both tests before the resin in Column No. 1 could reach full saturation.

It is also apparent from comparing radium loading on the resin at test completion against Column No. 3 discharge radium analysis that the eventual radium loading of the resin treating Panel water would be substantially lower than the resin treating Key Lake water. Although Column No. 3 discharge was 0.2 Bq/L Ra-226 (diss.) at test completion for both types of water the resin loading in No. 1 Column for the Panel test was only 1200 Bq/g Ra-226 compared to a resin loading of 4064 Bq/g Ra-226 in Key Lake Column No. 1.

This observation is an indication that the chemistry of the water being treated is of direct significance to the radium loading efficiency of the radium-selective complexer. The higher calcium content of the Panel water along with a lower radium concentration may have both contributed to lower loading efficiencies of the resin when compared to the Key Lake test efficiencies.

Based on the results of this testwork it can be anticipated that the treatment of contaminated water containing high levels of calcium could be expected to result in lower radium loading and consequent poorer radium removal efficiencies. The presence of other ions and complexes in the water being treated could also be a contributing factor although there was insufficient data generated in this testwork to define this with any degree of certainty.

4.0 RADIATION EXPOSURE POTENTIAL

The radiation measurements taken during the course of the testwork were evidence that radium-loaded resin would present some degree of radiation exposure potential under full-scale operating conditions. An estimate of this potential was accomplished by basing the calculations on previous estimates of radiation exposure potential of loaded resin carried out by other workers in previous work⁽²⁾.

The calculations were based on the following assumptions:

radium loading on the resin	- 6400 Bq/g
bulk density of resin when loaded	- 0.3 g/cm ³ of wet settled resin
column size	- 2.44 m diam. x 3.7 m
loaded resin bed volume	- 2.44 m diam. x 1.21 m (5.66 m ³)
column materials of construction	- 0.64 cm mild steel - 0.64 cm rubber lining
radon gas retention	- Case I - 0 - Case II - 10%

The estimates were accomplished for a loaded column under operating conditions (ie. flow of water through the column) as well as for a loaded column several weeks after shutdown where an increase in radiation due to the natural decay of radium was anticipated based on the test results. Estimates were developed for two cases, one with no radon gas retention in the column and one with 10% radon gas retention.

The radiation exposure potential 122 cm from the outside wall of a column containing resin loaded with 6400 Bq/g Ra-226 was estimated as 0.1 mR/h with no radon retention and 0.6 mR/h with 10% radon retention. The radiation values would rise to approximately 6 mR/h with loaded resin remaining under static conditions several weeks after column shutdown since the radium would decay into its daughter elements.

Since radon is chemically inert and relatively soluble in water it is unlikely that radon or radon daughters would be retained in the resin bed during the flow of water through the column. Therefore the lower value of 0.1 mR/h for radiation levels 122 cm from the column is likely the more probable value for radiation exposure potential of a column 2.44 m diam. x 3.7 m containing approximately 6 m³ of resin loaded with 6400 Bq/g radium. The dose rate would be 0.26 mR/h, 0.10 mR/h and 0.05 mR/h at a distance of 50 cm, 122 cm and 200 cm from the outside wall of the column respectively. These estimated radiation levels could be anticipated for the column when the resin approaches radium saturation.

Due to increasing radiation levels upon standing the resin would need to be discarded once it was fully loaded with radium or once it lost its efficiency in terms of its application in a water treatment scheme.

From these estimates it appears that low radiation exposure values of loaded resin could be expected under operating conditions in a large-scale operation. Normal safety procedures should be adequate in maintaining worker health and safety.

It should be noted that these radiation exposure values for loaded resin are only estimates. Further information and analyses would be required before drawing any firm conclusions with regards to radiation exposure under full-scale operating conditions.

5.0 DECONTAMINATION

The decontamination of equipment was evaluated briefly at the end of the test by washing the inside of the lead column in the Key Lake set with water. A wipe test was taken on the inside of the column after washing the column in order to obtain a measurement of alpha and beta radiation. No radioactivity could be detected.

From this simple test it appears that decontamination of equipment in contact with radium-loaded resin could simply be done by washing the equipment thoroughly with water. It should be kept in mind however that the laboratory columns were of plastic construction (C-Acrylic) and that actual materials of construction for full-scale columns (mild steel, rubber-lined) could behave differently in the sense that a more thorough washing procedure may be required.

6.0 DISPOSAL

The disposal of radium-loaded resin would be of concern in certain applications since it does contain a large amount of radium.

In a normal uranium mining operation it would be quite feasible to dispose of the radium-loaded resin in the tailings area either as-is or in a solidified form. Although there is no information on the stability of radium adsorbed on the resin complexer with respect to chemical re-dissolution or resin degradation it would be expected that the chemical stability of the resin would be at least equal to the stability of radium-barium sulphate sludges produced in current barium chloride treatment operations.

For economic reasons regeneration of the resin may be an attractive option for operators where the concentrated radium-rich eluate could be treated in existing barium chloride treatment facilities. This would need to be investigated in a laboratory test program since elution of radium-loaded resin has not been tested to date. Radium removal efficiencies of regenerated resin would also need to be determined in conjunction with this work.

The disposal of the radium-loaded resin with the mill tailings would eliminate to some extent any concern for increased radioactivity and external radiation dose rate that would occur with time if the loaded resin was stored separately. The gamma activity of loaded spent resin would increase to a relatively steady value in approximately three weeks depending on the retention of Rn-222 in the resin. The most significant gamma-emitting Ra-226 daughter is Bi-214 with Pb-214 being of lesser significance. Other daughters of Ra-226 are not a source of penetrating radiation.

Transfer of loaded resin to the tailings area could be simply and

safely accomplished by pumping the resin with the neutralized mill tailings slurry at a controlled rate. If short-term storage of loaded resin was necessary, continuous emersion in water would effectively protect workers from alpha and beta exposure.

Long-term storage of loaded resin also needs to be concerned with the eventual degradation of the ion exchange resin by exposure to the radiation emanating from the complexed radium-226 and its daughters. As discussed in Appendix E this degradation might be expected to occur over a period of tens of hundreds of years depending on the storage conditions of the resin.

Options for separate disposal of the radium-loaded resin in a suitable radioactive storage facility can include solidification with cement, bitumen, glass or modified vinyl ester resins⁽⁴⁾. Reductions in volumes of the immobilized material can be achieved by incineration of the resin followed by solidification of the ash with the solidifying agents. These options would need to be evaluated in terms of the release of any contaminants during the immobilization or incineration process as well as the long-term stability of the solidified products.

7.0 COST ESTIMATES

In order to assess the economic viability of a radium removal circuit utilizing the radium-selective ion exchange complexer an order-of-magnitude capital and operating cost estimate was accomplished for a tailings decant water treatment plant at a uranium facility typical of northern Saskatchewan. The design assumptions used for the estimate are given in Table 7-1 with the process flowsheet described in Figure 7-1. A conceptual layout of the process equipment is shown in Figure 7-2. It is stressed that the design values given in Table 7-1 are assumptions only and that further data would be required before reliable design values could be established. However, the assumed values are thought to be adequate for the purpose of an order-of-magnitude cost estimate.

The decant water feed rate to the treatment circuit was chosen at $150 \text{ m}^3/\text{h}$ in order to allow a direct comparison of costs with waste management cost estimates developed earlier for the National Uranium Tailings Program and detailed in the Kilborn/Melis cost study report (Model B)⁽⁵⁾.

The treatment circuit selected for the cost estimate includes sand filtration for removal of suspended solids with radium removal being accomplished by three upflow resin columns in series. Treated water is discharged directly from the last resin column directly to the local watershed. Facilities are included for returning sand filter backwash and spent resin to the tailings pond.

The capital costs of the treatment facility have been estimated at \$2,731,400 in mid-1984 Canadian dollars. The estimate is summarized in Table 7-2 and the estimate details are given in Appendix F. The capital costs include all the costs associated with the treatment facility including buildings, pumping of decant water, power supply and initial resin inventory.

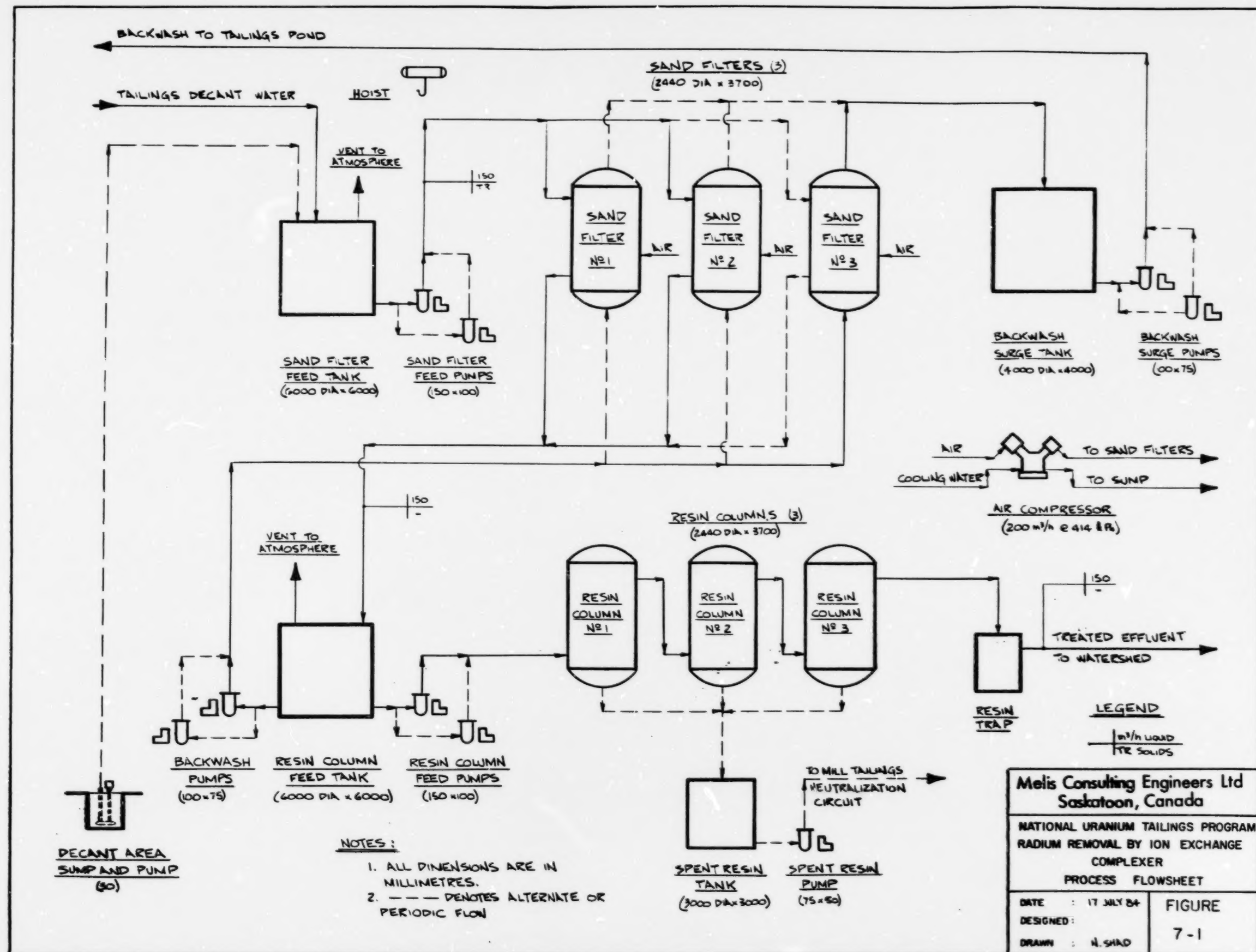
TABLE 7-1

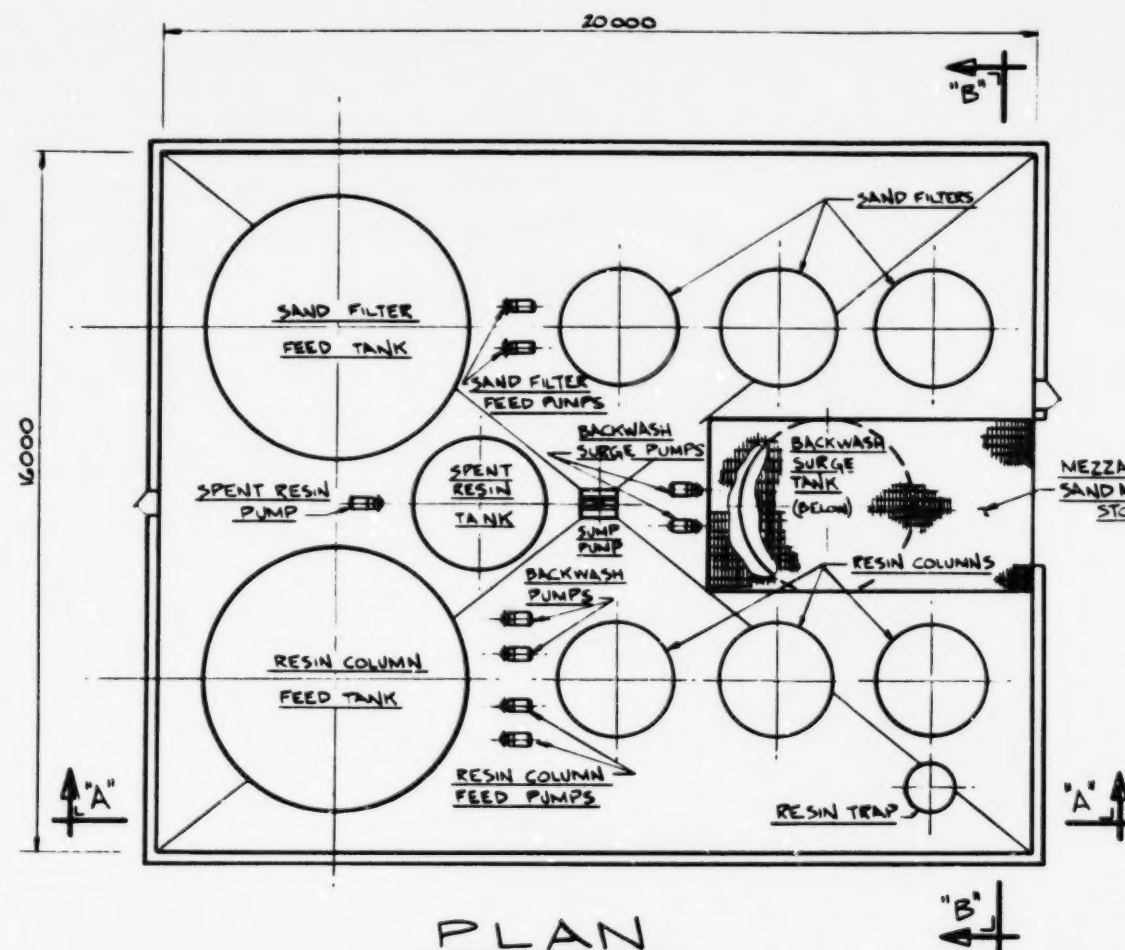
COST ESTIMATE DESIGN ASSUMPTIONS(1)

Tailings decant water flow (m^3/h)	-150
Tailings decant water radium concentration (Bq/L)	-10
Sand filtration specific flowrate ($\text{m}^3/\text{h}/\text{m}^2$)	-16
Number of sand filters	-3
Resin column feed (m^3/h)	-150
Resin column operation	-upflow in series
Number of resin columns	-3
Resin column specific flowrate ($\text{m}^3/\text{h}/\text{m}^2$)	-33
Initial service life of resin in lead column-bed volumes	-100,000
Average service life of resin in lead column-bed volumes	-75,000
	-days
Volume of resin in each column-fresh resin (m^3)	-9.14
	-loaded resin (m^3)
	-7.01
Cumulative radium removal efficiency of No. 1 Column (%)	-75(2)
Cumulative radium removal efficiency of No. 2 Column (%)	-20(2)
Cumulative radium removal efficiency of No. 3 Column (%)	-5(2)
Radium concentration in loaded resin-Bq/g Ra-226	-2500(2)
	-Bq/cm ³ Ra-226
	-750
Annual resin consumption (m^3 fresh resin)	-21.8

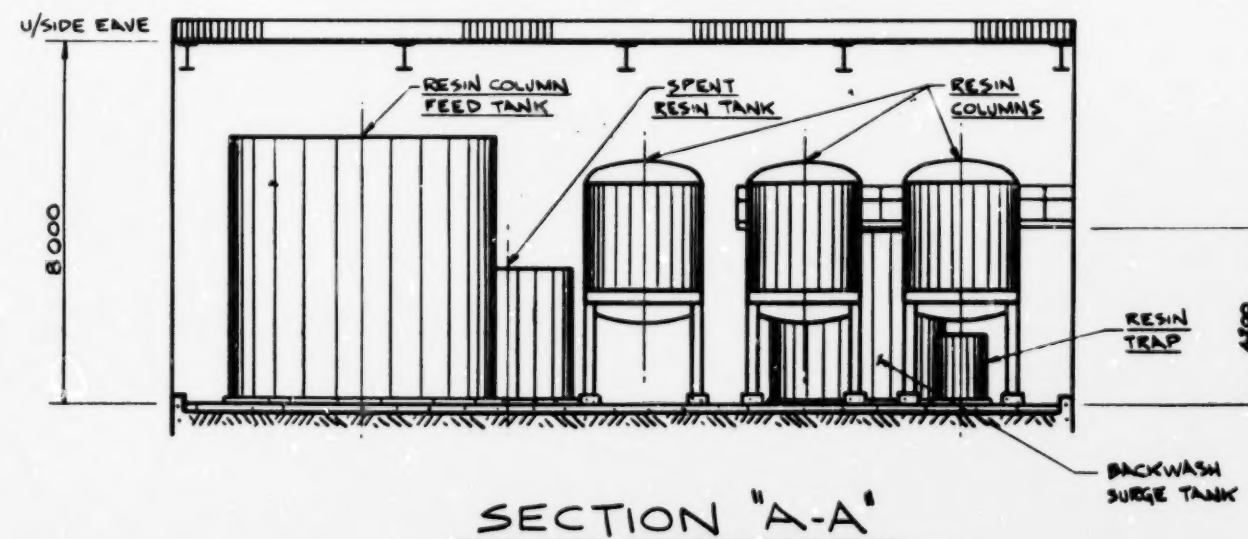
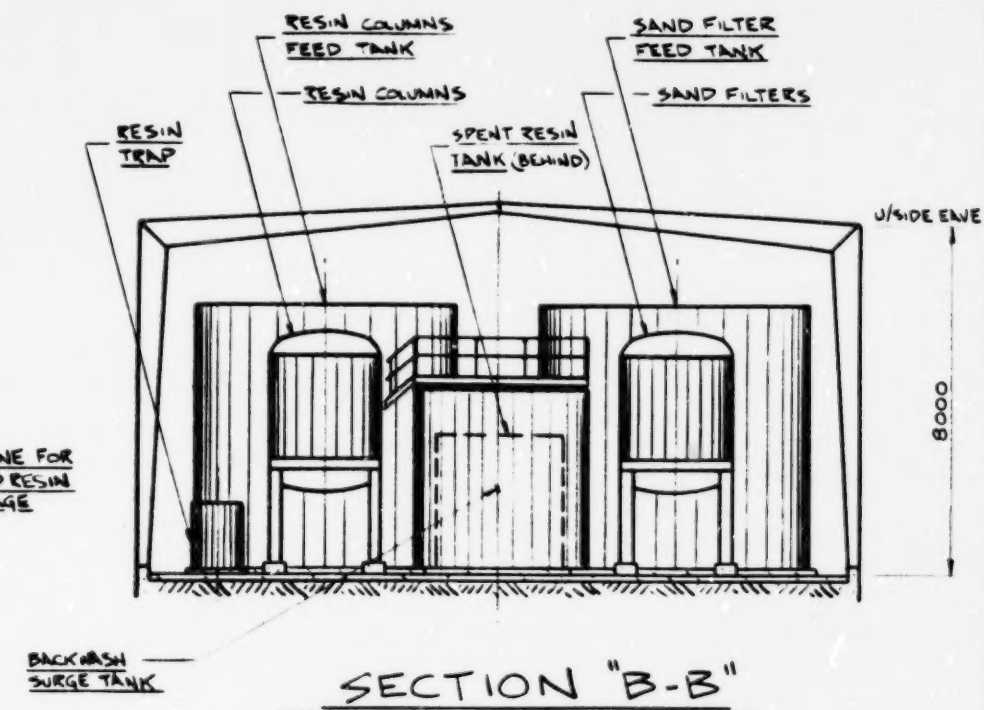
(1) Design assumptions are approximate only and are based on the test data. Further work would be necessary to establish more reliable design values.

(2) Assumed values for calculating resin consumption.





PLAN



SCALE:
MILLIMETRES x 1000
1 0 1 2 3 4 5

Melis Consulting Engineers Ltd Saskatoon, Canada	
NATIONAL URANIUM TAILINGS PROGRAM RADIUM REMOVAL BY ION EXCHANGE COMPLEXER CONCEPTUAL LAYOUT	
DATE : 17 JULY 84	FIGURE
DESIGNED :	7-2
DRAWN : J. SHAD	

TABLE 7-2TAILINGS DECANT WATER TREATMENT PLANTCAPITAL COST ESTIMATE

<u>Direct Costs</u>	<u>\$</u>
Buildings	324,000
Decant Water and Backwash Line	26,500
Power Line and Substation	64,600
Process Equipment	759,300
Mechanical Installation	151,900
Piping	182,200
Electrical	182,200
Instrumentation	<u>91,100</u>
Total Direct Costs	1,781,800
<u>Indirect Costs</u>	
Construction Indirects (8%)	142,500
Engineering, Procurement, Construction Management (12%)	213,800
Capital Spares	25,000
Resin Inventory	<u>320,000</u>
Sub-total	2,483,100
Contingency (10%)	<u>248,300</u>
TOTAL ESTIMATED CAPITAL COSTS	<u><u>2,731,400</u></u>

The annual operating costs of the resin treatment process described in Figure 7-1 are estimated at \$569,065 in mid-1984 Canadian dollars. At a treatment rate of $150 \text{ m}^3/\text{h}$, 350 days per year, this annual cost is equivalent to a treatment cost of $\$0.45/\text{m}^3$ of water treated. The operating cost estimate is summarized in Table 7-3 and detailed in Appendix F. The annual resin consumption of 21.8 m^3 is based on an assumed radium-loading capacity of 750 Bq/cm^3 for the resin in the lead column. The resin purchase price of $\$11,742/\text{m}^3$ or $\$250(\text{U.S.})/\text{cu.ft.}$ was obtained from Dow Chemical Canada Inc.

The comparative capital costs of a tailings decant water treatment circuit of the same capacity utilizing barium chloride precipitation and sand filtration was estimated at $\$3,188,600$ in first quarter 1984 Canadian dollars ⁽⁵⁾. The comparative operating costs were estimated at $\$488,244$ per year or $\$0.40/\text{m}^3$.

The cost comparisons indicate that the costs of a radium removal process utilizing the radium-selective ion exchange complexer under the assumptions made would be in the same order-of-magnitude as the costs of a barium chloride/sand filtration system. It should also be noted however that the cost of the resin treatment process would be expected to be higher than the cost of a barium chloride precipitation/settling pond treatment process ⁽⁵⁾.

TABLE 7-3TAILINGS DECANT WATER TREATMENT PLANTANNUAL OPERATING COST ESTIMATE

<u>Item</u>	<u>\$</u>
Manpower	114,435
Resin	256,630
Supplies	50,000
Power	110,000
Heating	8,400
Roads and Yards	<u>2,500</u>
Sub-total	541,965
Contingency (5%)	<u>27,100</u>
TOTAL ESTIMATED ANNUAL OPERATING COSTS	<u>569,065</u>

8.0 CONCLUSIONS

Laboratory investigations for evaluating the radium-selective complexer, Dowex XFS 43230.00, have shown that this resin complexer is very efficient in removing radium from the two types of contaminated water tested.

The test results have shown that the resin efficiency is not affected by the radium concentration in the contaminated water being treated. Similar radium removal efficiencies were observed after treating approximately the same number of bed volumes for both Key Lake grinding water, assaying 60 Bq/L Ra-226(diss.) and Panel tailings decant water, assaying 6.7 Bq/L Ra-226(diss.). For Panel water the cumulative efficiency for No. 1 Column was 97.5% for 28,336 bed volumes and 91.5% for 69,350 bed volumes. For Key Lake water the cumulative efficiency was 97.7% for 21,687 bed volumes.

The results also showed that the service life of the resin in terms of bed volumes of water treated would be restricted by feed radium concentration due to a finite loading capacity of the resin. In the Key Lake test radium loading in No. 1 Column was 4,064 Bq/g Ra-226 after treatment of only 21,687 bed volumes of Key Lake grinding water. On the other hand in the Panel test the resin in No. 1 Column only contained 1200 Bq/g Ra-226 after treatment of 69,350 bed volumes of Panel tailings decant water.

It appeared from the results that, in a three-column operation, the loading capacity of the resin in the lead column would be affected by the chemistry and radium concentration of the contaminated water being treated. The No. 3 Column discharge analysis was 0.2 Bq/L Ra-226 (diss.) for both the Key Lake and Panel tests in spite of the resin in Panel No. 1 Column being well below the ultimate loading capacity of the resin.

The radium removal efficiency of the resin was not affected by the higher calcium content of the Panel tailings decant water but high calcium levels may have an effect on the loading capacity, and hence service life, of the resin when treating tailings decant water which has previously been neutralized with lime at high pH. This fact is substantiated by the Panel results where the loaded resin contains much higher levels of calcium as compared to the Key Lake loaded resin. For this reason the loading capacity of the resin could in fact have been restricted with extended operation by the substantial presence of calcium ions in the Panel water.

Under upflow operating conditions increasing specific flowrates did not affect the radium removal efficiency of the resin when treating Panel water containing 6.7 Bq/L Ra-226 (diss.). From these results it appears that the resin will operate efficiently under upflow conditions at 100% bed expansion which is equivalent to a specific flowrate of $33 \text{ m}^3/\text{h}/\text{m}^2$ or 1 bed volume per minute. Further work would be required in order to determine an optimum value for design purposes.

Breakthrough in Column No. 1 was not achieved in either the Key Lake or Panel tests with the limited amount of bulk water sample available for test purposes. Consequently the laboratory tests did not allow an actual physical measurement of the ultimate loading capacity of the resin. It was possible however to extrapolate the Key Lake data to provide an estimate of the ultimate loading capacity of the resin.

This extrapolation of data indicated that the ultimate loading capacity of the resin when treating Key Lake type water was in the range of 7,000 to 7,500 Bq/g Ra-226. Based on loaded (exhausted) resin this would be equivalent to a radium-loading of 2,100 to 2,250 Bq/cm³ of wet settled resin. Allowing for the volume loss that occurs soon after initiating flow through the resin (caused by an exchange of calcium ions for sodium ions on the resin) the equivalent ultimate radium-loading capacity of the resin as received from the supplier would be in the range of 1,580 to 1,700 Bq/cm³ (1.2 to 1.3 mCi/ft³) of new wet settled resin.

This loading value would obviously be dependent on the type of contaminated water being treated. The results of the Panel test indicated that lower resin loadings should be expected when treating effluents containing high levels of calcium.

In a three-column system the service life of the resin in the lead column would be dictated by the level of radium in the discharge of the last column. Once this level exceeded the regulatory guidelines of 0.37 Bq/L Ra-226 (total) the resin in the first column would need to be discarded. In this program it was not possible to determine what the "breakthrough" would have been under these conditions but the test results did seem to indicate that No. 3 Column discharge would have reached a level of 0.37 Bq/L Ra-226 (total) before the resin in the lead column could reach its ultimate saturation with respect to radium loading. In the tests a total of 21,700 bed volumes of Key Lake water and 69,350 bed volumes of Panel water were treated with the final discharge not exceeding 0.25 Bq/L Ra-226 (total). This meant that the resin in the lead column for both tests still had radium-loading capacity available but due to program restrictions it was not possible to determine the total number of bed volumes that could be treated before reaching 0.37 Bq/L Ra-226 (total) in the last column discharge.

The discharge analyses towards the end of the test program seemed to indicate a decrease in radium removal efficiency for the last two columns as the radium level in the discharge of the first column increased. Although there is insufficient data to draw any firm conclusions it appears that some form of resin poisoning may have occurred during the treatment period which may have affected the resin in the last two columns. Because of this the loading capacity of the resin in Column No. 2 (and No. 3) could be detrimentally affected in a sequential operation when Column No. 2 (or No. 3) became the lead column in series.

It was estimated from radiation exposure calculations that the radiation dose rates of radium-loaded resin in a rubber-lined steel ion exchange

column would be 0.1 mR/h at a distance of 122 cm from the column. This level of radiation should not present any problems under full-scale operating conditions since the radiation levels estimated were well below the allowable limits for uranium mill workers. Further information would be required before drawing any firm conclusions regarding radiation exposure potential.

From the test results and from the radiation estimates it was identified that radiation levels would increase to approximately 6 mR/h for a column containing loaded resin if it was left under static conditions for several weeks after shutdown. This increase in radiation would be caused by the retention of radon and radon daughters in the resin bed.

Due to these increasing radiation levels the resin would need to be discarded once it was fully loaded with radium or once it lost its efficiency in terms of its application in a water treatment process.

One disposal option for loaded resin would be to discard it in a uranium tailings area along with the neutralized mill tailings when used for treating contaminated water at an operating minesite. The discarded resin would need to be dispersed on a wet basis in the tailings ensuring placement of the resin below the tailings surface. Solidification methods or transport to a suitable tailings area would need to be considered for spent resin in treatment applications other than normal mining operations. The long-term stability of the resin would need to be addressed in terms of radium re-dissolution potential as well as radium release due to resin degradation.

9.0 RECOMMENDATIONS

Although the radium-selective complexer, Dowex XFS 43230.00, has been shown to be effective in removing radium from uranium mining effluents there are certain areas which warrant further investigations as a result of the findings in this study.

The ultimate capacity of the resin, estimated as 7,000 to 7,500 Bq/g Ra-226 in this program, should be confirmed by follow-up work. The saturation point of the resin could be determined by operating three columns in series where the lead column contained a smaller amount of resin in order to achieve saturation with a minimum of bulk water sample. Since it appears that high calcium levels in contaminated water could have an effect on ultimate resin loading values this work would need to be done on contaminated water with low levels of calcium, such as minewater, and on contaminated water with higher levels of dissolved solids such as neutralized tailings decant water.

From an operating viewpoint the service life of the resin would be controlled by the level of radium in the last column of any treatment system. The current guidelines of 0.37 Bq/L Ra-226 (total) for radium concentrations in treated mill effluents would be the governing factor in determining the loading capacity of the resin. For this reason the radium loading on the resin in the first column should be determined at the time the second column discharge reaches a level of 0.37 Bq/L Ra-226 (total) in a two-column system or when the level in the third column discharge reaches 0.37 Bq/L Ra-226 (total) for a three-column system. This would then define the true capacity of the resin from a practical application standpoint.

Since it was not possible in this program to determine the radium removal efficiency of Column No. 2 in a sequential operation of three columns in series further work should be undertaken to determine this. It is feasible that resin poisoning could have occurred in

the last two columns of the three-column operation in the laboratory tests due to the chemistry of the water being treated. Consequently the loading capacity of the resin in Column No. 2 (and No. 3) could be restricted when Column No. 2 (and No. 3) became the lead column in a sequential operation. Laboratory tests should be carried out to define this in terms of design requirements for full-scale operations.

As upflow columns were used in this test program it would be worthwhile from a design point-of-view to determine the operating characteristics of resin columns when operated in a downflow mode. This type of operation could enhance the applicability of the resin since the number of columns required to ensure full saturation of the resin in the lead column could be reduced. This could mean that a two-or-three-column system would be sufficient to ensure full saturation of the resin in a lead column while maintaining final discharge levels of less than 0.37 Bq/L Ra-226 (total).

The contaminated water samples used in this test program contained very little suspended solids and hence the effect of suspended solids on resin efficiency could not be measured. Since the application of this resin would be well suited to treating contaminated minewater from uranium operations, which generally contains a certain degree of suspended solids, tests should be done to determine if the resin efficiency or loading capacity is affected by the presence of suspended solids in the water being treated. The tests could be done in an upflow or a downflow system with periodic backwashing stages.

Economic considerations would dictate that attempts be made to regenerate the resin for increasing its service life prior to disposal. This would only have application where a conventional barium chloride treatment process would be present as part of the

milling operations in order to allow treatment of a highly concentrated eluate produced from regeneration of the resin. This work would entail the evaluation of various eluants as well as evaluating the radium removal efficiency of regenerated resin as compared to new resin.

Although the resin is efficient in adsorbing radium on its surface the long-term chemical stability of loaded resin is not known in terms of potential re-dissolution of radium for various disposal options. The stability of the radium on the resin surface should therefore be determined for different disposal options such as:

- separate storage in a storage pond
- as an admixture with neutralized mill tailings
- as a solidified product by immobilization with various solidifying agents.

The concern for chemical stability of the radium-loaded resin would be particularly important in terms of the make-up of tailings water when the loaded resin is discarded with mill tailings. The concentration and type of ions present in the tailings water would be directly related to the ore and type of milling process of a uranium operation. It is therefore possible that re-dissolution of radium could occur due to the varying chemistry of tailings water for different uranium operations.

A second aspect of long-term stability of the radium on the resin surface would be related to the effect of degradation of the resin matrix with time. This should be assessed in conjunction with any chemical stability investigations.

10.0 REFERENCES

1. L.A. Melis, Report to National Uranium Tailings Program, "Development of the Disposal Technology Research Component of the National Uranium Tailings Program", March, 1983.
2. T.D. Boyce and S. Boom, "Removal of Soluble Radium from Uranium Minewaters by a Selective Complexer", Preprint No. 82-63, Society of Mining Engineers of AIME, Littleton, Colorado, February, 1982.
3. R.E. Rozelle, K.E. Ma, "A New Potable Water Radium/Radon Removal System", A.W.W.A. Annual Conference, Las Vegas, Nevada, June, 1983.
4. R.A. Speranzini and L.P. Buckley, "Treatment of Spent Ion-Exchange Resins for Disposal", Second IAEA Research Co-ordination Meeting, Toronto, Ontario, September, 1981.
5. Kilborn/Melis Report to National Uranium Tailings Program, "Cost Study on Waste Management at Three Model Canadian Uranium Mines", March, 1984.

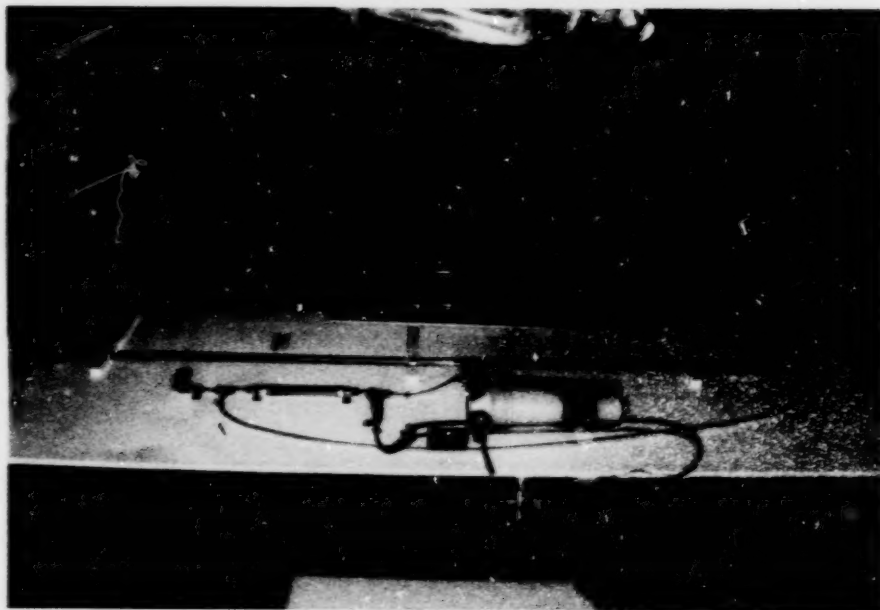


PLATE 1

Test equipment showing columns



PLATE 2

Test equipment showing columns
and feed tanks

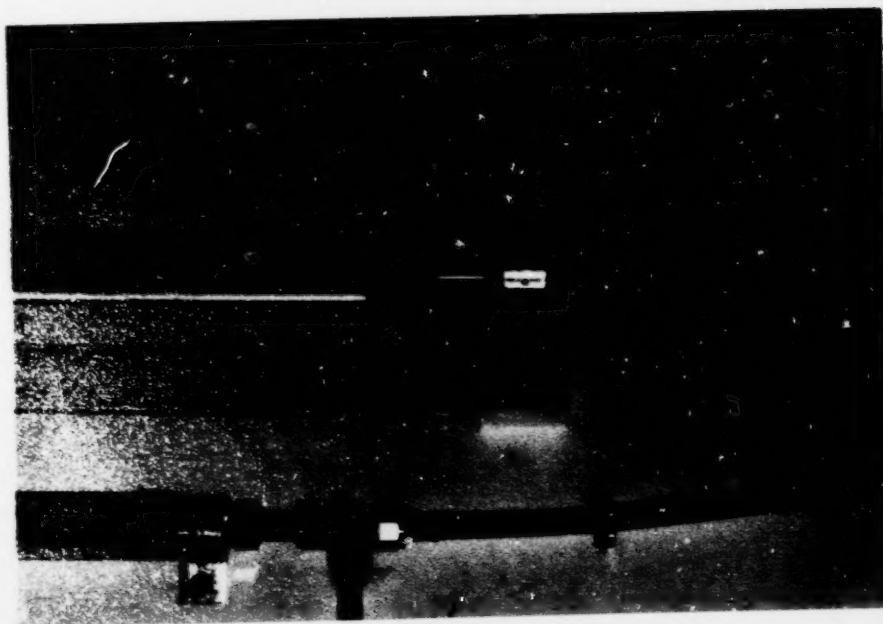


PLATE 3

Precipitate in Key Lake Column No. 1 (above resin)



PLATE 4

Precipitate in Panel Column No. 1 (above resin)

APPENDIX A

DOW RADIUM COMPLEXER XFS 43230.00
MATERIAL SAFETY DATA SHEET

MATERIAL SAFETY DATA SHEET PAGE: 1
DOW CHEMICAL U.S.A. MIDLAND MICHIGAN 48640 EMERGENCY PHONE: 517-636-4400

EFFECTIVE DATE: 13 JUL 82

PRODUCT CODE: 37328

PRODUCT NAME: XFS 43230.00 EXPERIMENTAL RADIUM COMPLEXER. MSD: 1167

INGREDIENTS (TYPICAL VALUES-NOT SPECIFICATIONS) : % :

ACTIVE INGREDIENT : 18-35:
MOISTURE : 65-82:

SECTION 1

PHYSICAL DATA

BOILING POINT: NOT APPLICABLE : SOL. IN WATER: INSOLUBLE
VAP PRESS: NOT APPLICABLE : SP. GRAVITY: DENSITY 45-50 LB/FT3
VAP DENSITY (AIR=1): NOT APPLIC. : % VOLATILE BY VOL: 76-82

APPEARANCE AND ODOR: LIGHT YELLOW TO AMBER SOLID (BEADS) - ODORLESS.

SECTION 2

FIRE AND EXPLOSION HAZARD DATA

FLASH POINT: NOT APPLIC. : FLAMMABLE LIMITS
METHOD USED: NOT APPL. : LFL: NOT APPLIC. UFL: NOT APPLIC.

EXTINGUISHING MEDIA: DRY CHEMICAL.

SPECIAL FIRE FIGHTING EQUIPMENT AND HAZARDS:

POSSIBLE FIRE COMBUSTION PRODUCTS: ALKYL BENZENES, VINYL BENZENES,
NAPHTHALENE, BENZALDEHYDES, PHENOL, CARBON DIOXIDE, WATER, SULFUR
OXIDES, ORGANIC SULFONATES.

PRODUCT IS NOT COMBUSTIBLE UNTIL MOISTURE IS REMOVED, THEN RESIN
STARTS TO BURN IN FLAME AT 230C.

SECTION 3

REACTIVITY DATA

STABILITY: ----

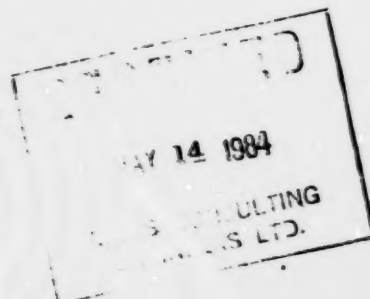
INCOMPATIBILITY: WARNING: NITRIC ACID AND OTHER STRONG
OXIDIZING AGENTS MAY CAUSE EXPLOSIVE REACTIONS WHEN MIXED WITH
ORGANIC MATERIALS SUCH AS ION EXCHANGE RESINS. BEFORE USING
STRONG OXIDIZING AGENTS, CONSULT SOURCES KNOWLEDGEABLE IN HANDLING
SUCH MATERIALS. WHEN RESIN COMES IN CONTACT WITH SALT SOLUTIONS,
ACIDS ARE FORMED.

HAZARDOUS DECOMPOSITION PRODUCTS: ----

HAZARDOUS POLYMERIZATION: WILL NOT OCCUR.

(CONTINUED ON PAGE 2)

(R) INDICATES A TRADEMARK OF THE DOW CHEMICAL COMPANY



M A T E R I A L S A F E T Y D A T A S H E E T P A G E : 2
DOW CHEMICAL U.S.A. MIDLAND MICHIGAN 48640 EMERGENCY PHONE: 517-636-4400

EFFECTIVE DATE: 13 JUL 82

PRODUCT CODE: 37328

PRODUCT (CONT'D): XFS 43230.00 EXPERIMENTAL RADIUM COMPLEXER. MSD: 1167

SECTION 4 SPILL, LEAK, AND DISPOSAL PROCEDURES
ACTION TO TAKE FOR SPILLS: SWEEP UP.

CAUTION: MAY BE SLIPPERY.

DISPOSAL METHOD: SALVAGE IF POSSIBLE, OTHERWISE BURY IN AN APPROVED
LANDFILL. DISPOSE OF CONTAMINATED MATERIAL ACCORDING TO THE REGU-
LATIONS FOR THE CONTAMINATE.

SECTION 5 HEALTH HAZARD DATA

EYE: MECHANICAL INJURY ONLY.

SKIN CONTACT: MECHANICAL INJURY ONLY.

SKIN ABSORPTION: NOT ABSORBED THROUGH SKIN.

INGESTION: LOW SINGLE DOSE AND REPEATED DOSE ORAL TOXICITY; USUALLY
CONSIDERED TO PASS THROUGH GUT WITHOUT ABSORPTION.

INHALATION: NO GUIDE FOR CONTROL KNOWN. NOT LIKELY TO POSE A HAZARD AS
IT IS LOW IN TOXICITY.

SYSTEMIC & OTHER EFFECTS: NOT KNOWN - MAY CAUSE DEPLETION OF ESSENTIAL
METALS AT HIGH CONCENTRATION.

SECTION 6 FIRST AID

EYES: IRRIGATION OF THE EYE IMMEDIATELY WITH WATER FOR FIVE MINUTES
IS GOOD SAFETY PRACTICE.

SKIN: CONTACT WILL PROBABLY CAUSE NO MORE THAN IRRITATION. WASH
OFF IN FLOWING WATER OR SHOWER. WASH CLOTHING BEFORE REUSE.

INGESTION: NO EFFECT EXPECTED.

INHALATION: REMOVE TO FRESH AIR IF EFFECTS OCCUR. CONSULT MEDICAL
PERSONNEL.

NOTE TO PHYSICIAN:

EYES: INJURY IS UNLIKELY.

SKIN: MAY CAUSE MILD IRRITATION.

RESPIRATORY: NO EFFECT EXPECTED.

ORAL: NO EFFECT EXPECTED.

SECTION 7 SPECIAL HANDLING INFORMATION

VENTILATION: GOOD ROOM VENTILATION USUALLY ADEQUATE FOR MOST OPERATIONS.
RESPIRATORY PROTECTION: NONE NORMALLY NEEDED. IF DUSTS GENERATED, USE
APPROVED DUST RESPIRATOR.

(CONTINUED ON PAGE 3)

(R) INDICATES A TRADEMARK OF THE DOW CHEMICAL COMPANY

M A T E R I A L S A F E T Y D A T A S H E E T P A G E : 3
DOW CHEMICAL U.S.A. MIDLAND MICHIGAN 48640 EMERGENCY PHONE: 517-636-4400

EFFECTIVE DATE: 13 JUL 82

PRODUCT CODE: 37328

PRODUCT (CONT'D): XFS 43230.00 EXPERIMENTAL RADIUM COMPLEXER. MSD: 1167

SECTION 7 SPECIAL HANDLING INFORMATION (CONTINUED)

PROTECTIVE CLOTHING: NONE REQUIRED.

EYE PROTECTION: NOT NORMALLY NECESSARY.

SECTION 8 SPECIAL PRECAUTIONS AND ADDITIONAL INFORMATION

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE: PRACTICE REASONABLE
CARE AND CAUTION.

ADDITIONAL INFORMATION: REVISIONS 7/13/82 -- INGREDIENT STATEMENT, SECTION 1.

LAST PAGE

(R) INDICATES A TRADEMARK OF THE DOW CHEMICAL COMPANY
THE INFORMATION HEREIN IS GIVEN IN GOOD FAITH, BUT NO WARRANTY,
EXPRESSED OR IMPLIED, IS MADE. CONSULT THE DOW CHEMICAL COMPANY
FOR FURTHER INFORMATION.

APPENDIX B

RADIUM-226 ANALYTICAL METHOD

RADIUM 226 ANALYTICAL METHOD

Radium is removed from prepared sample solutions by co-precipitation with lead sulphate. The lead sulphate is then dissolved in alkaline EDTA, barium carrier is added and barium sulphate is preferentially precipitated by lowering the pH to 4.5. Radium co-precipitates with the barium sulphate which is re-dissolved and re-precipitated to remove traces of other radio-nuclides (lead, bismuth, thorium). This purified barium (radium) sulphate is filtered on a membrane filter, contacted with a zinc sulphide-mylar disc and the alpha disintegrations counted on a bare-photomultiplier scintillation counter. The ingrowth of the radium daughters increases the sensitivity of the method and the degree of this ingrowth must be taken into account when calculating results.

The relative standard deviation for this method is approximately $\pm 10\%$ of the amount present for levels above 0.2 Bq. Below 0.2 Bq this RSD increases gradually to $\pm 100\%$ at 0.005 Bq, which is the detection limit for a 100-minute count with a background of 0.03 counts/min.

It should also be noted that the accuracy of radium determinations is also greatly dependent, and affected by, other factors such as sample collection, sample handling, sample preservation and sample storage. All these factors would have contributed to some extent to certain anomalous values included in this report.

All solution samples were prepared by filtration through a 45-micron filter followed by acidification with concentrated nitric acid at a concentration of 10 mL/L.

APPENDIX C

WATER AND RADIUM BALANCES
PANEL INDIVIDUAL BATCHES

FIGURE C-1
 PANEL WATER AND RADIUM BALANCE
 Jan. 31 to Feb. 19, 1984

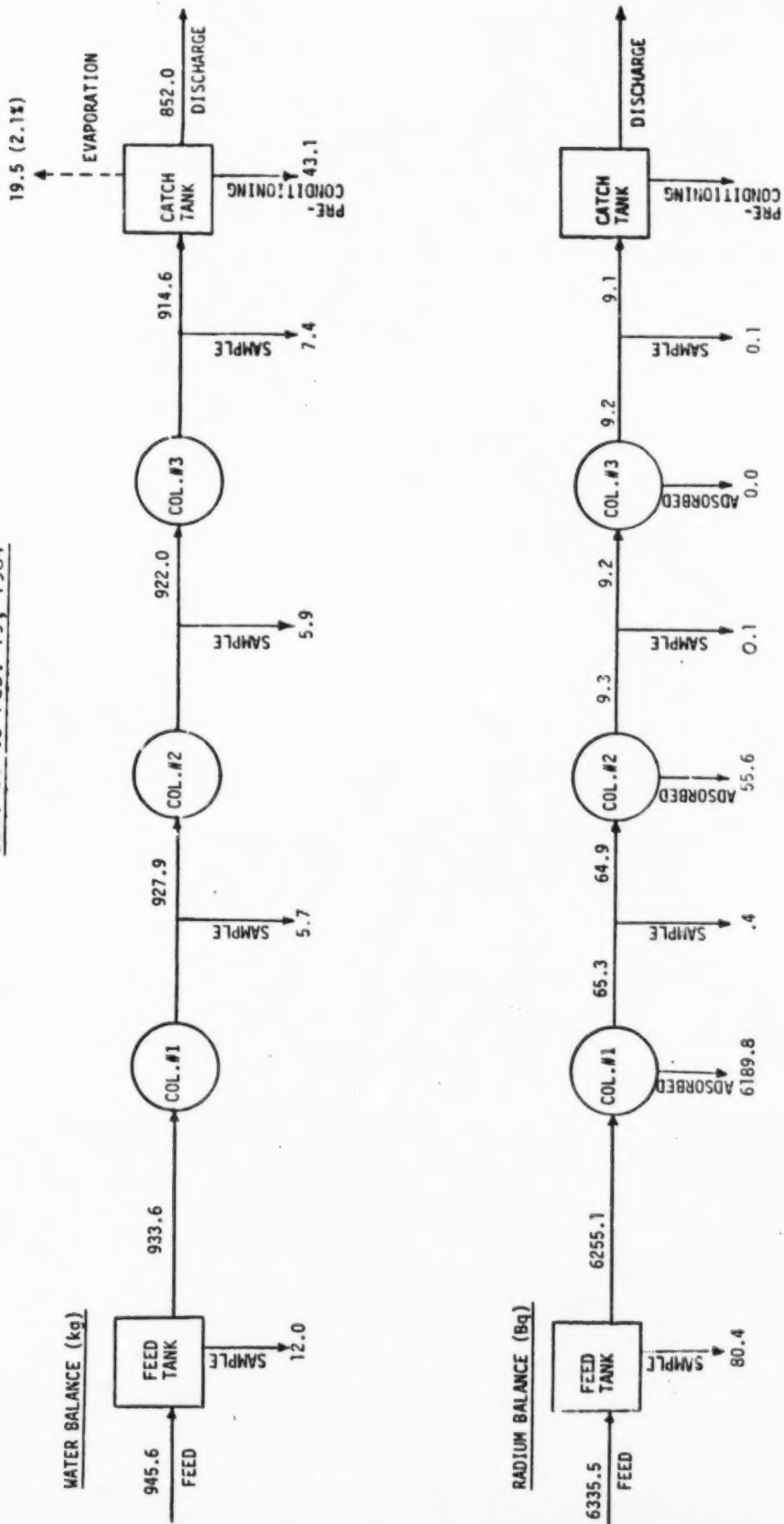


FIGURE C-2
 PANEL WATER AND RADIUM BALANCE
 Feb. 19 to Mar. 11, 1984

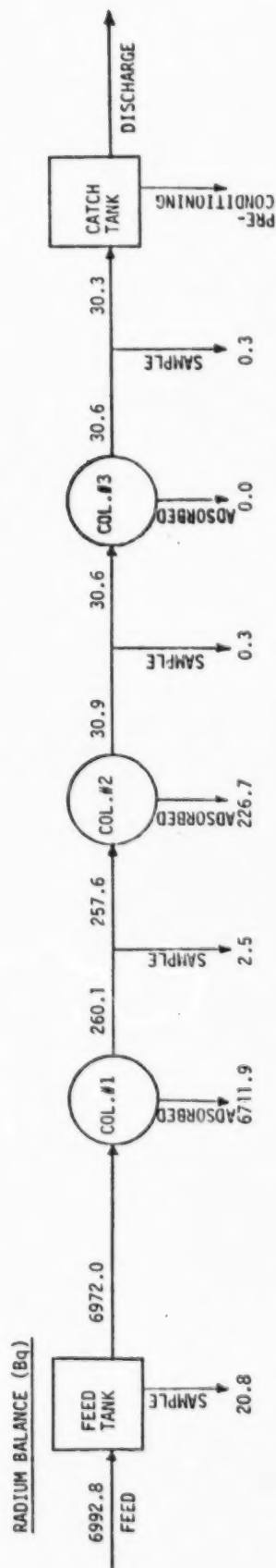
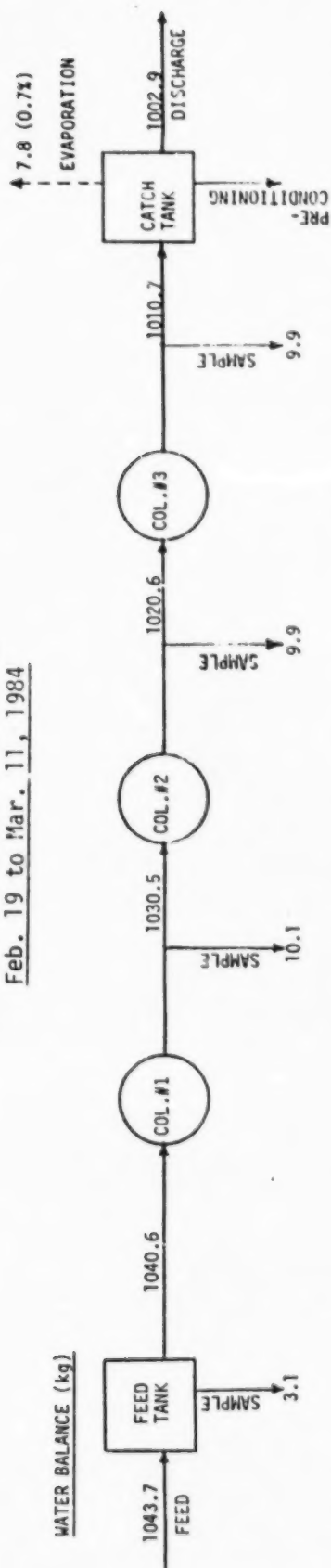


FIGURE C-3
 PANEL WATER AND RADIUM BALANCE
 Mar. 11 to Mar. 31, 1984

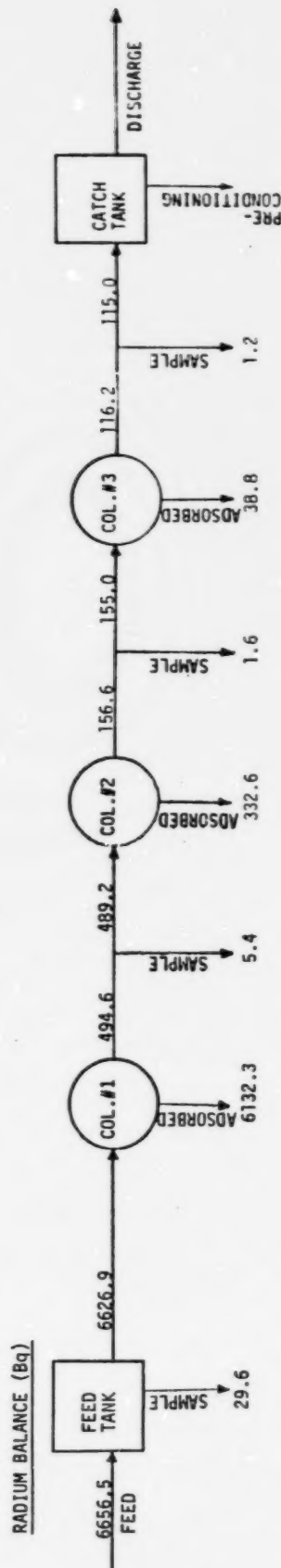
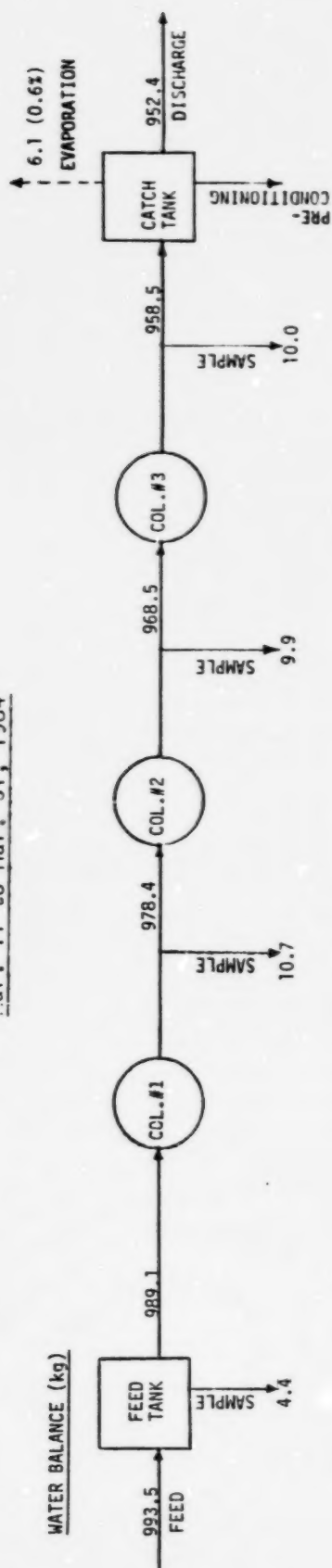


FIGURE C-4
 PANEL WATER AND RADIUM BALANCE
 Mar. 31 to April 14, 1984

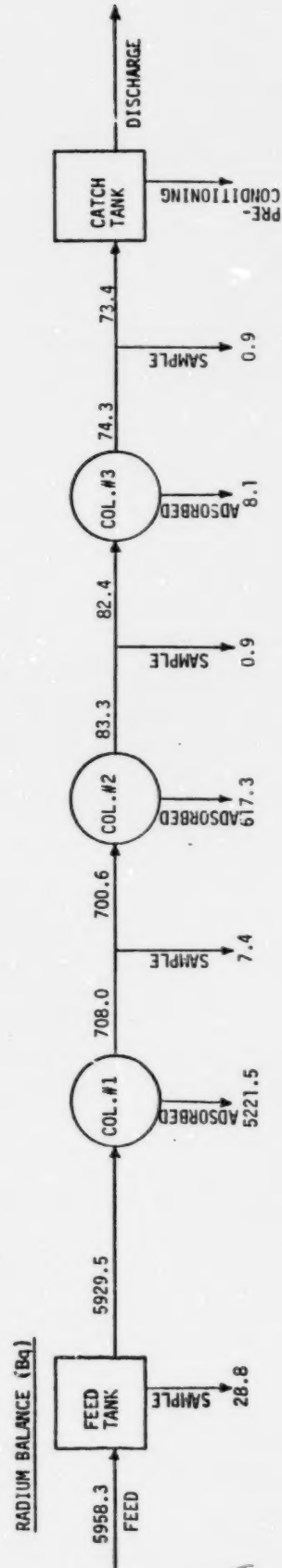
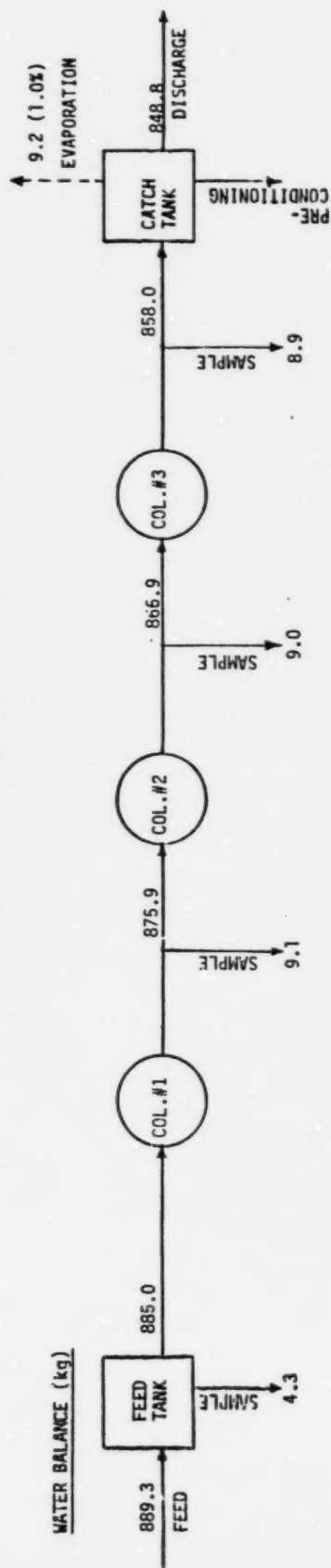
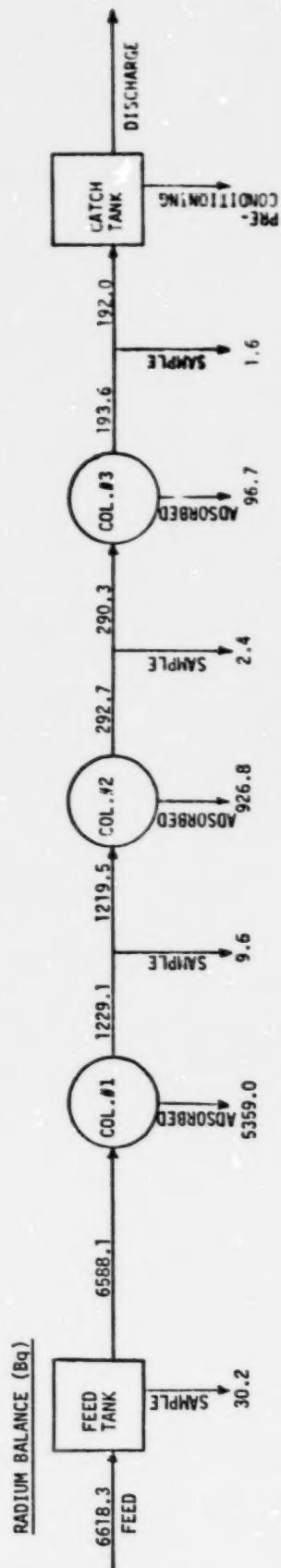
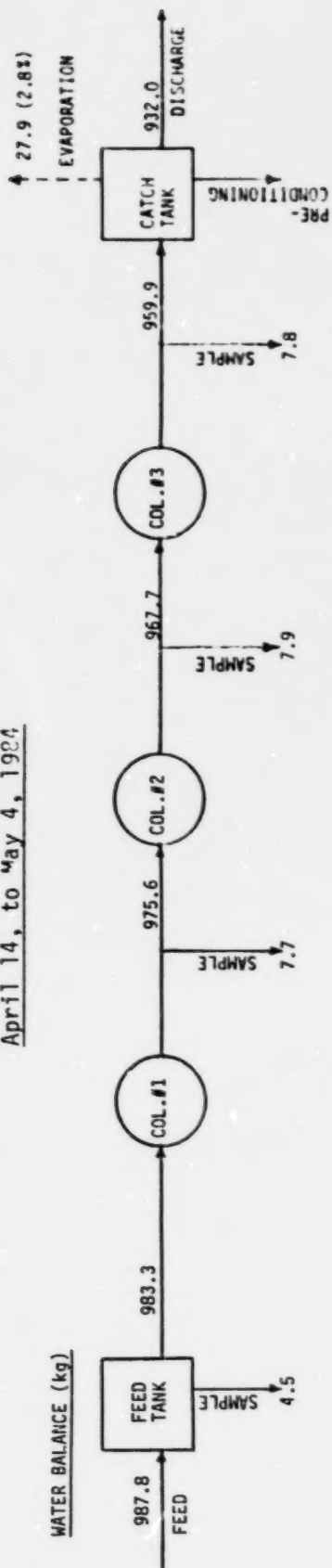


FIGURE C-5
PANEL WATER AND RADIUM BALANCE
April 14, to May 4, 1984



APPENDIX D

WATER AND RADIUM BALANCES
KEY LAKE INDIVIDUAL BATCHES

FIGURE D-1

KEY LAKE WATER AND RADIUM BALANCE

Feb. 16 to Feb. 27, 1984

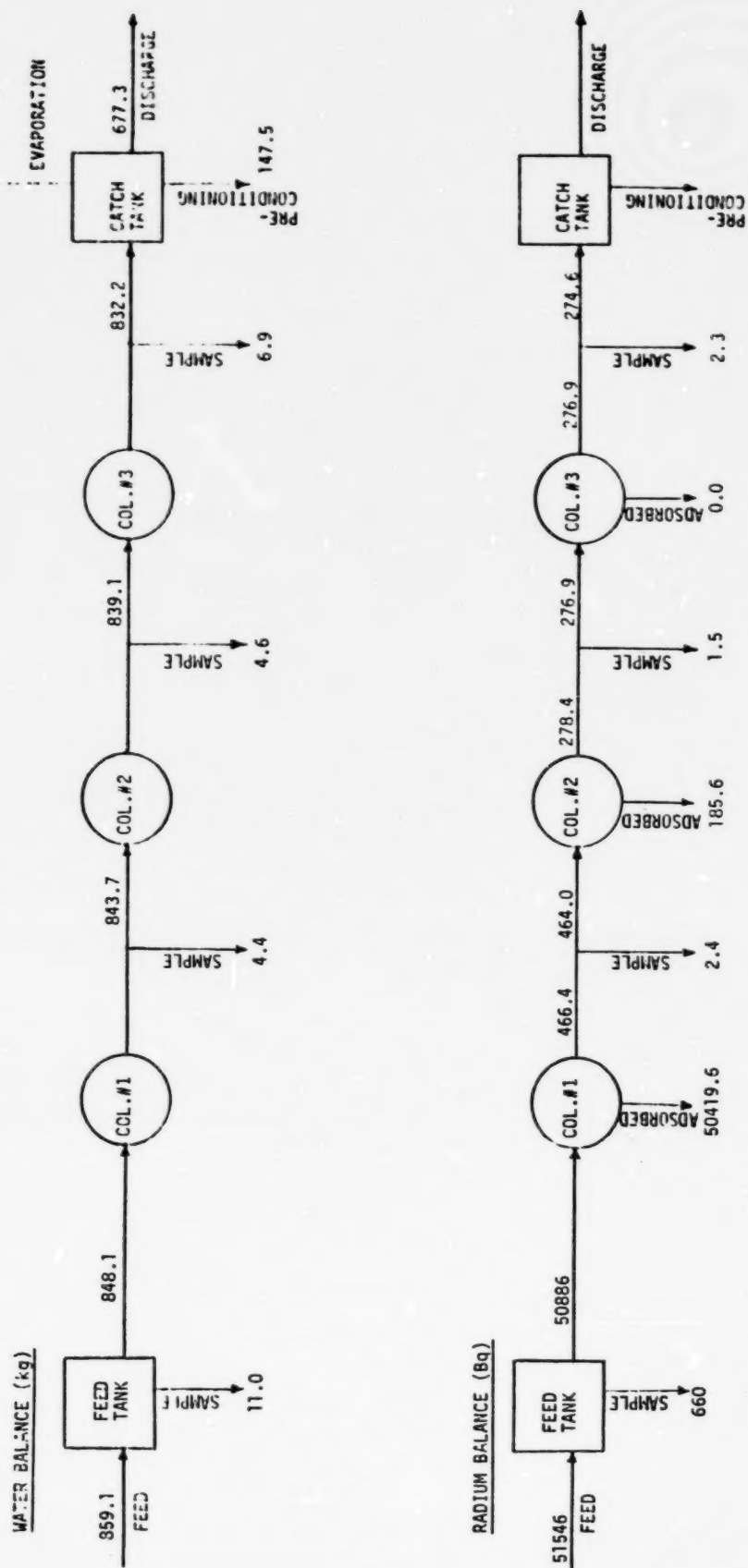


FIGURE D-2
KEY LAKE WATER AND RADIUM BALANCE
Feb. 27 to March 10, 1984

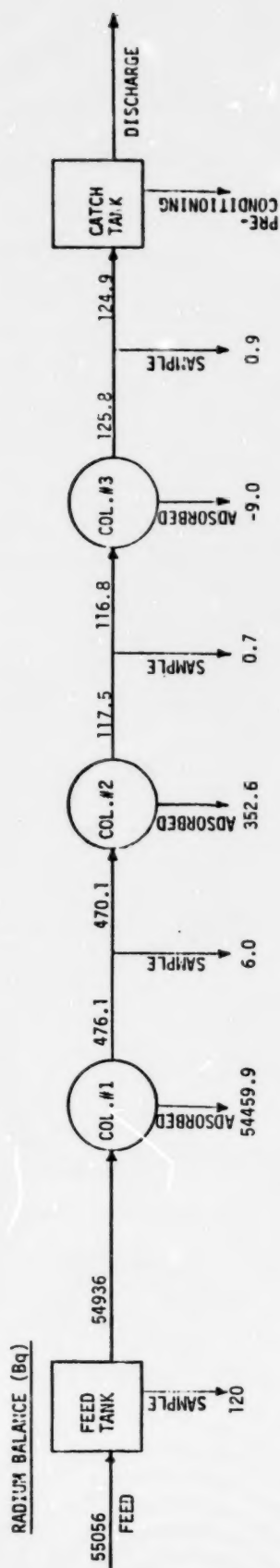
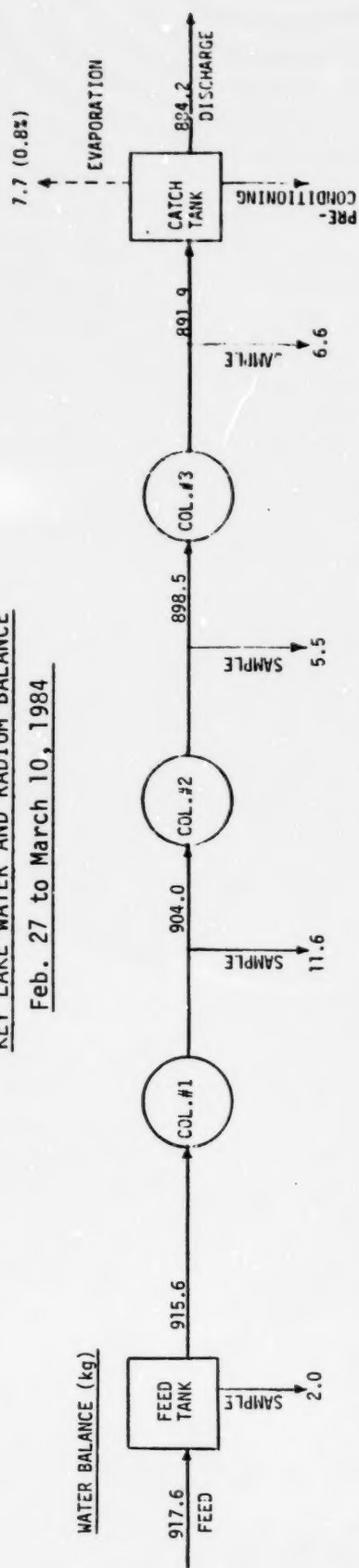


FIGURE D-3
KEY LAKE WATER AND RADIUM BALANCE
Mar. 10 to Mar. 23, 1984

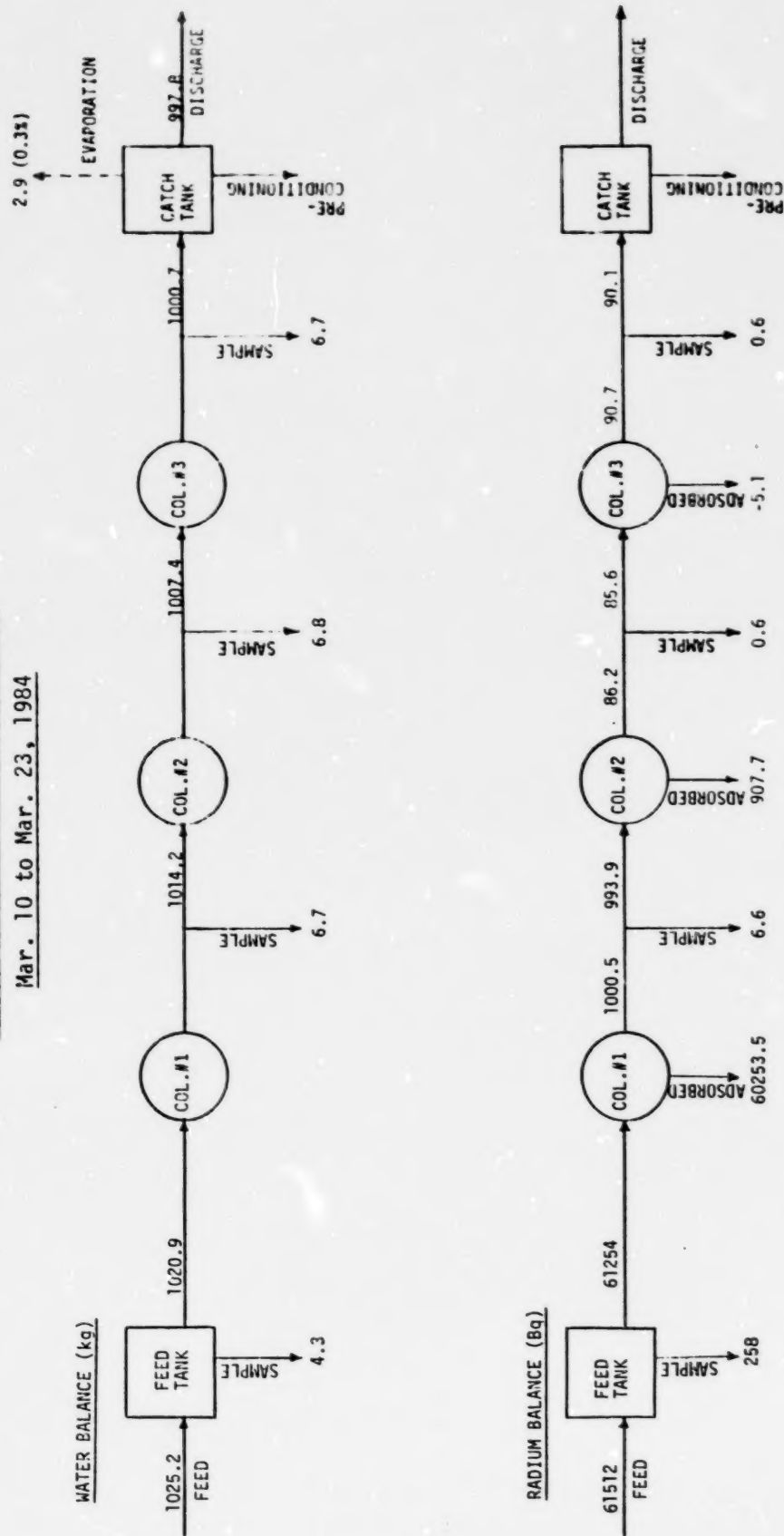


FIGURE D-4

KEY LAKE WATER AND RADIUM BALANCE

Mar. 23 to April 3, 1984

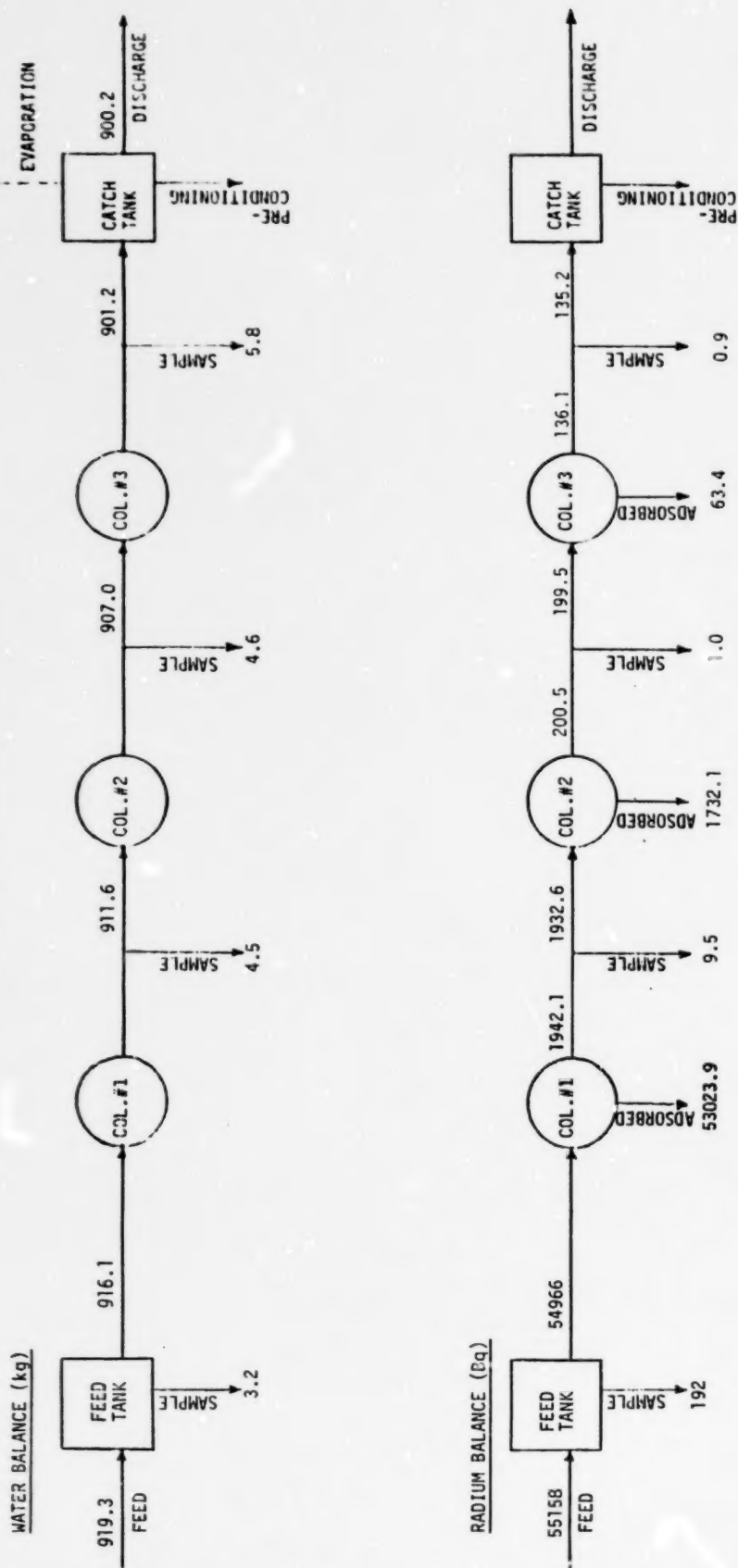
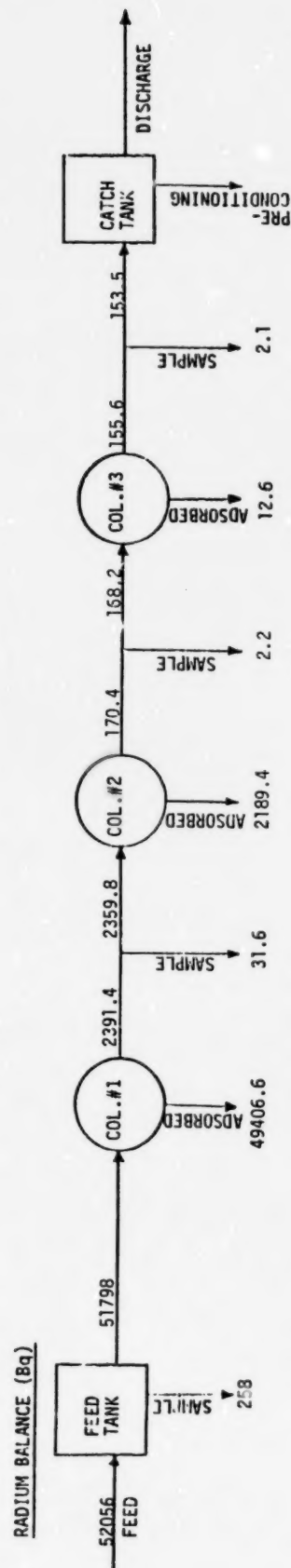
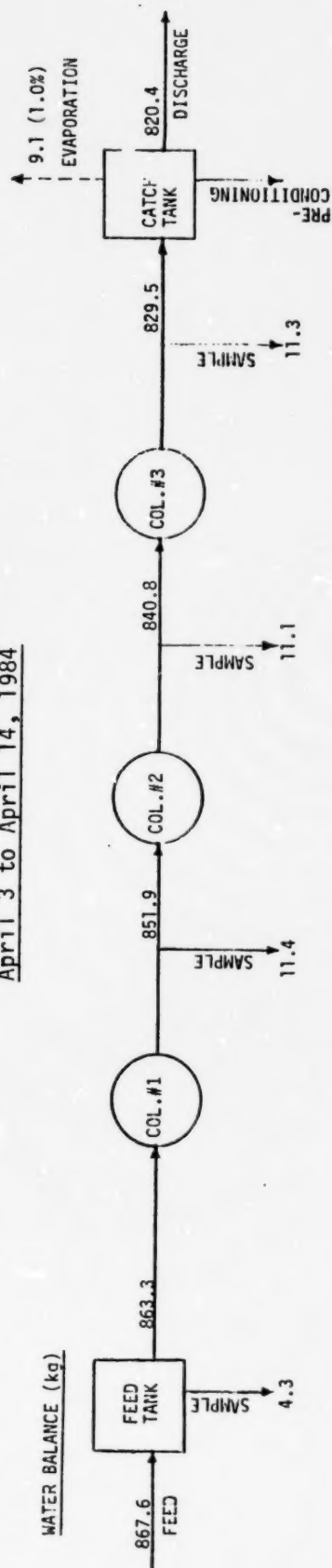


FIGURE D-5
KEY LAKE WATER AND RADIUM BALANCE
April 3 to April 14, 1984



APPENDIX E

RADIATION EXPOSURE POTENTIAL ESTIMATES

MELIS CONSULTING ENGINEERS LTD.

Metallurgical Engineering Services

155 A.E. Adams Crescent
Saskatoon, Saskatchewan, Canada

S7K 5M6
(306) 242-1021

May 22, 1984

Dr. R. Woods
Chemistry Department
University of Saskatchewan
Saskatoon, Saskatchewan

Dear Dr. Woods:

re: DSS Contract File 26SQ-23241-3-1655
Determining the Applicability of the Use of a Radium
Selective Ion Exchange Resin in the Removal of Radium from
Canadian Uranium Mining Effluents

Part of the work related to the above contract includes the estimation of radiation exposure potential for the radium-selective complexer when fully loaded with radium under typical plant conditions.

As you are aware this estimation was to be accomplished by you under a sub-contract to the project. I have listed the required data and basis for the calculations on the attached sheet. Reference can be made to the radiation exposure estimates calculated in the paper "Removal of Soluble Radium from Uranium Minewater by a Selective Complexer, T.D. Boyce and S. Boom" of which you have a copy. I also enclose a sketch of a typical flowsheet of a resin treatment system for your reference.

You will note that I have included two cases for the estimate calculations. Case A assumes no radon gas retention while Case B assumes a 10% radon gas retention. A radiation exposure estimate is required for both cases when the resin in the lead column has reached its full saturation point (assumed to be 6400 Bq/g Ra loading).

I have also provided a gamma measurement taken from the laboratory test column 10 days after the test completion. Under operating conditions (ie flow of water through the column) gamma levels were approximately 0.07 mr/h with a background reading of 0.02 mr/h. This increased and stabilized at approximately 1.2 mr/h 10 days after test completion. This value should only be used as a reference point for your calculations since in practice the resin would be disposed of immediately after reaching radium saturation.

MELIS CONSULTING ENGINEERS LTD.

Dr. R. Woods

University of Saskatchewan

May 22, 1984

Page 2

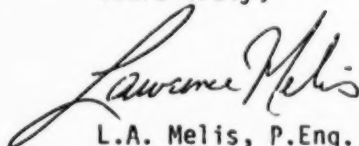
Once you have completed your calculations I would like to meet with yourself and G. Smithson of SRC to discuss your findings. One day next week will hopefully be suitable.

You also had mentioned that you had information in your files regarding disposal methods of low-level wastes similar to this radium-loaded resin. I would appreciate any information that you may be able to provide with respect to making recommendations for disposal of the radium-saturated resin.

As initially agreed it is understood that your charges for this work will be at rate of \$350/day and not to exceed a total of \$1122. This letter authorizes you to proceed with the work as detailed. If you have any questions please contact me. The requested information is required by May 31, 1984 for inclusion in my draft report to the Scientific Authority.

Thank you for your assistance in this project.

Yours truly,



L.A. Melis, P.Eng.
Principal

Melis Consulting Engineers Ltd.

LAM:dm

APES Cert. of Authorization No. 418
encl.

DATA FOR CALCULATING RADIATION EXPOSURE
POTENTIAL FOR A FULLY-LOADED RADIUM COMPLEXER

Assumptions

1. Radium loading on the resin - 6400 Bq/g (dry resin)
2. Bulk density of resin after Ca exchange - 0.3 g(dry)/cc of wet resin
3. Column materials of construction - 0.64 cm ($\frac{1}{4}$ ") mild steel
- 0.64 cm ($\frac{1}{4}$ ") rubber lining
4. Resin bed volume - before Ca exchange - 7.11 m^3 (2.44m diam.x1.52m)
- after Ca exchange - 5.66 m^3 (2.44m diam.x1.21m) -
(at Ra saturation point)
5. Column Size 2.44 m diam. x 3.7 m
6. Radon retention - Case A - none
- Case B - 10%
7. Method of operation - downflow at $150 \text{ m}^3/\text{h}$

Gamma Measurement (1.9 cm diam. plexiglass column. 10 days after test completion)

1.2 mr/h for resin loaded to 6400 Bq/g Ra

6 Kirk Crescent,
Saskatoon, Sask.,
S7H 3B2.

30 May, 1984

L.A. Melis,
Melis Consulting Engineers Ltd.,
155 A.E. Adams Crescent,
Saskatoon, Sask. S7K 5M6.

Dear Lawrence,

re: DSS Contract File 26SQ-23241-3-1655
Determining the Applicability of the Use of a Radium
Selective Ion Exchange Resin in the Removal of Radium from
Canadian Uranium Mining Effluents

Following our discussions, I have recalculated the dose rates given on pages 3 and 5 of my report "Radiation Exposure Potential and Disposal of Radium-Loaded Dow XF43230/XFS43230 Ion-Exchange Resins" for a column of resin 2.44m diam. and 1.21m high (the original calculations were for a bed of resin 2.44m diam and 1.52m high).

For the 1.21m height, the following values should be substituted under section 6 (page 3):

CASE I (no radon)	0.76 mrem/hr	(in place of 1.2 mrem/hr)
CASE II (10% radon)	4.2 mrem/hr	(in place of 5.1 mrem/hr)
Equilibrium (100% radon)	42 mrem/hr	(in place of 51 mrem/hr)

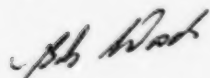
Under Health Hazrad (page 6), the multiplying factor becomes $0.4 \times 0.33 = 0.13$ since the active height of the column (i.e. height of the resin bed) is 1.21m, not 3.7m.

The estimated radiation exposures 122 cm from the outside wall (page 5) become 0.1 mrem/hr during column operation (Case I: no radon) and 0.6 mrem/hr (Case II: 10% radon retention). The value rises to about 6 mrem/hr several weeks after column shutdown.

As noted in our discussions, the dose rate will be higher closer to the column and will fall off as the distance between the resin and the radiation detector is increased. Estimated dose rates are: 0.26 mrem/hr at 50 cm, 0.10 mrem at 122 cm, and 0.05 mrem/hr at 200 cm (Case I; no radon). The values are regarded as approximate because of uncertainties in the build-up factors used (see not 5, page 3 of the report).

A search of the literature dealing with radiation attenuation suggests that it will not be possible to estimate the dose rate exactly in the present instance because some of the essential information is not available. Boyce and Boom's approach should give a reasonable approximation, but I would strongly recommend making some actual measurements with the radium-loaded resin if at all possible.

Yours truly,

A handwritten signature in dark ink, appearing to read "R.J. Woods". The signature is written in a cursive, slightly slanted style.

R.J. Woods,
Professor of Chemistry

RADIATION EXPOSURE POTENTIAL AND DISPOSAL OF
RADIUM-LOADED DOW XF43230/XFS43230 ION-EXCHANGE RESINS

R.J. Woods, Department of Chemistry,
 University of Saskatchewan, Saskatoon.

Summary

The model developed by Boyce and Boom (Boyce, 1982) has been used to estimate the probable radiation exposure from radium-loaded ion exchange resin contained in a rubber-lined steel vessel. The estimates indicate that the radiation levels will not present a serious health hazard if ion exchange resins are used to remove radium-226 from uranium mill effluents. However, some questions are raised concerning the input data used by Boyce and Boom. Disposal options are briefly discussed from the point of view of radiation hazard and effects.

ESTIMATION OF RADIATION EXPOSURE POTENTIAL

Boyce and Boom (Boyce, 1982) used the following equation to estimate the radiation exposure 122 cm from the wall at the mid-point of a cylindrical 1/4" steel tank, 8ft in diameter and 5 ft high, containing 250 cu ft radium-complexed ion exchange resin.

$$\text{Dose Rate (mrem/hr), } I_z = \frac{\Gamma A}{d^2} \times e^{-\mu x_{H_2O}} \times e^{-\mu x_{\text{steel}}} \times B$$

where I_z = dose rate at point z (mrem/hr)

Γ = specific gamma constant (mrem-m²/Ci-hr)

A = activity (Ci)

d = distance from radioactive source to point z (m)

μ = linear attenuation coefficient (water/steel)(cm⁻¹)

x = distance photons travel in the water/steel to point z (cm)

B = a build-up factor to allow for radiation scattered to point z
 (i.e. not travelling directly from the source to point z)

The total radiation exposure at point z was estimated by dividing the total activity contained in the resin into 35 equal point sources that were arranged in a uniform (in two dimensions) manner throughout the resin tank, and then summing the radiation exposure due to each point source at point z.

Two possible situations were considered by Boyce and Boom: CASE I, no retention of radon by the resin and, CASE II, retention of 10% of the radon released by the resin. In the latter case the total activity present in the loaded resin is higher due to the presence of radon and its daughters, and the values of the specific gamma constant, attenuation coefficients, and build-up factor will differ from those for Case I because of the different photon energies present. The numerical data used by Boyce and Boom is summarized in the following table.

Quantity (units)	CASE I	CASE II
Weighted average photon energy (MeV)	0.23	0.83
Specific gamma constant (mrem-m ² /Ci-hr)	0.00397	825
Total activity (Ci)#	2 (Ra-226)	2 (Ra-226) plus 0.2 of each of the Ra daughters
$\mu(\text{water/resin})(\text{cm}^{-1})$	0.137	0.0774
$\mu(\text{steel})(\text{cm}^{-1})$	1.24*	0.0652*

(The values of d, x, and B vary with the position of the point source)

1 Curie (Ci) = 3.7×10^{10} Becquerel (Bq)

* not given by Boyce and Boom; value from Grodstein, 1957.

NOTES

1. In Case I, the Boyce and Boom give a weighted average photon energy of 0.23 MeV, though the value of the water attenuation coefficient they use corresponds to an energy of 0.15 MeV (Grodstein, 1952).
2. The authors do not give a reference for the value of 0.00397 for the specific gamma constant in Case I. While this value is consistent with the calculated dose rates given in Table VIII of Boyce and Boom's paper, it appears to give a value for the total dose at point z well below the 0.2 mrem/hr quoted in the body of the paper (see below). Unfortunately, virtually all values for the specific gamma constant for radium-226 given in the literature refer to radium-226 in equilibrium with its daughter elements, which are much higher (cf. Case II).

Scandium-47 gives 0.16 MeV gamma radiation (~70% of the disintegrations) and has $\Gamma = 560$ mrem-m²/Ci-hr. Ra-226 would be expected to have a specific gamma activity about 4/70 of this since only 4% of the Ra-226

disintegrations give photons (0.188 MeV), i.e. $r = \sim 30 \text{ mrem-m}^2/\text{Ci-hr}$. This value gives a value for the total exposure at point z that is more consistent with, though still about six times higher than, the value calculated by Boyce and Boom.

3. The specific gamma constant given for Case II, $825 \text{ mrem-m}^2/\text{Ci-hr}$, is the standard value for Ra-226 in equilibrium with its daughter elements and encased in 0.5 mm platinum. The value for the 'bare' material (without the 0.5 mm Pt) should be $909 \text{ mrem-m}^2/\text{Ci-hr}$ (Attix, 1969; p. 748). Use of this value would increase the reported dose rates (Boyce and Boom, Table IX) by about 10%.
4. The total activity used in the calculations for Case II includes Ra-226 and all its daughter elements in equilibrium amounts, i.e. activities equal to that of the radium-226 (the results are subsequently divided by ten since it is assumed that only 10% of the radium daughter elements are present with the resin). This will tend to overestimate the exposure since Pb-210, Bi-210 and Po-210 will not be formed in significant amounts until several years have elapsed and will not approach equilibrium for about 100 years.
5. No reference is given to the source of the build-up factors used. This could be a serious omission since these factors play an important part in the calculation and are subject to a good deal of uncertainty (Jaeger, 1968).
6. The calculations were repeated using the data given in the table above following the method used by Boyce and Boom, leading to the following values for the total dose (mrem/hr) (Boyce and Boom's values are in parentheses):

CASE I (no radon)	1.04×10^{-4}	(0.2)	($r = 0.00397 \text{ mrem-m}^2/\text{Ci-hr}$)
	1.2		($r = 30$ ")
CASE II (10% radon)	5.1	(4.5)	(assumes all Ra-226 daughters present)
At equilibrium (max. = 100% radon and daughter elements)	51	(45)	

CONCLUSIONS

Although some questions have been raised concerning the input data used by Boyce and Boom, their general approach and conclusions appear to be valid and their estimates are probably of the right order. Sufficiently so to conclude that the radiation risk is not very large and that this should not be the deciding factor in evaluating the process. If necessary, more sophisticated three-dimensional models could be used to estimate the radiation exposure (see, for example, Jaeger, 1968) though this would take some considerable effort that might be better spent in actual measurements with radium-loaded resin.

APPLICATION OF THE BOYCE-BOOM MODEL

Several conditions will be different in the present study to those used in developing the Boyce-Boom model. The effect of these changes on the estimated radiation exposure is discussed.

Activity

The present study assumes a radium-226 loading of 6400 Bq/gram resin. Boyce and Boom assumed a total loading of 2 Ci radium-226 (7.4×10^{10} Bq) in a cylinder 244 cm in diameter and 152 cm high containing resin and water with a combined density of 1 g/cm³, i.e. a total mass of 7.11×10^6 g and a loading of 10,400 Bq radium-226/g resin. Thus, in the present study, the exposure doses should be approx. 40% lower than those estimated by Boyce and Boom.

The radium loading in the present instance will be reduced by a further 33% since the value of 6400 Bq/g is given for the dry resin and in use this will be mixed with water in the proportion 0.3 g dry resin/cm³ water. The combination of the lower radium loading and dilution with water leads to radiation exposures in the present case that are between 10% and 15% of those estimated by Boyce and Boom.

Vessel Size

The proposed tank is 244 cm diameter and 370 cm high, compared with 244 cm diameter and a height of 152 cm in the model. Comparison of the larger tank height with the values shown in Tables VIII and IX of Boyce and Boom's paper indicates that this will increase the exposures by a factor of about two, or less.

Effect of the Rubber Lining

This is likely to be marginal since the effectiveness of a material as gamma ray shielding is related to its density - 0.64 cm rubber lining would reduce the exposure by about the same factor as 1 to 2 cm water. Steel is a denser material, justifying its inclusion as a separate term in the calculation.

Health Hazard

Combining the probable effects of lower radium loading, use of 'wet' resin, and a longer tank as described above means that the dose estimates of Boyce and Boom should be multiplied by $0.4 \times 0.33 \times 2 = 0.3$ to obtain estimated doses applicable to the present conditions. This gives estimated

radiation exposures 122 cm from the outside wall of the tank and 185 cm from the base of about 0.07 mrem/hr during column operation (Case I, assuming no radon retention) or about 1.5 mrem/hr (Case II, 10% radon retention). In both cases the radiation level would rise to about 20 mrem/hr several weeks after column shutdown. (These values assume a column loading of 6400 Bq/g Ra and should therefore be maximum values.)

There seems to be little evidence that radon and radon daughters will be retained by the column during operation and the lower value (Case I) is the more probable value. This could be maintained after shutdown by keeping a continual flow of water through the resin.

Exposure rates of the order of 1 to 20 mrem/hr should not present a serious problem in ensuring worker safety and, even if the dose estimates are low by several hundred percent, the dose rates would not be excessively high. (A 'Radiation Worker' could be exposed to 2.5 mrem/hr continuously for fifty 40-hour weeks a year before reaching the allowed annual radiation dose, though exposures are normally kept well below this.)

DISPOSAL OPTIONS

Several factors that should be considered in discussing final disposal of the radium-loaded ion exchange resin are outlined below.

Radiation Buildup

Radon is chemically inert and relatively soluble in water so that it will probably be removed from the ion exchange column by the normal water flow during operation. Boyce and Boom note that radon decay products do not appear to accumulate on the resin during seven months continuous use. However, once the water flow is stopped the radon will no longer be removed and it and its daughter elements will build up until they are in equilibrium with the complexed radium-226, leading to an increase in activity and external radiation dose rate. The activity will increase to a relatively steady value over the first 2 to 3 weeks as the daughters between radon and lead-210 grow in, and then increase more slowly over a period of years as the remaining daughters Pb-210, Bi-210 and Po-210 build up. The total activity will decay slowly at a rate characteristic of the radium-226, i.e. with a half-life of 1620 years.

During the initial build up of radon and its daughters, the total activity will increase to six times the initial value (there will be five daughter elements in equilibrium with the original radium-226). The total activity will increase to nine times the radium-226 activity over the longer time span, taking a little over 100 years to reach the maximum activity.

Dose rates will not necessarily increase in proportion to the increased activity since the mix of photon energies present will also change.

Radiation Damage to Resin on Storage

The ion exchange resin will eventually be degraded by exposure to the radiation from the complexed radium-226 and its daughters. Relatively little information is available about specific ion exchange resins but an absorbed dose of between 1 and 100 Mrad is likely to be needed to cause significant breakdown and release of the complexed cations (see, for example Alian, 1984). At a radium-226 loading of 6400 Bq/g, the resin will be exposed to about 7000 rad/yr of mixed radiation and degradation might be expected over a period of some tens to hundreds of years. However, this should be checked under the conditions to be used for final disposal since the rate of degradation will be affected by such factors as moisture content, presence or absence of air (oxygen), etc.

Disposal Options

Ion exchange resins are used to remove radioactive contaminants during the operation of nuclear power reactors and a certain amount of information is available about possible methods of disposal. These include incineration to concentrate the radioactive material, and/or immobilization using cement, bitumin, or glass (see, for example Speranzini, 1981 and the references cited therein).

In a uranium mine-mill context, the preferred option might be to bury the loaded ion exchange resin with radium-barium sulfate sludge since this would minimize handling and may help retain the radium once the resin has degraded. A second alternative might be to chemically regenerate the resin for further use and to precipitate the radium-226 in the normal manner with barium chloride and soluble sulfate, subsequently disposing of the relatively active radium-barium sulfate solids (these should be no more active than the wastes from a mill processing high-grade uranium ores).

REFERENCES

- A. Alian, Ahmed Dessouki and Nasef B. El-Assy, 1984. "Ion Exchange Resins as High-Dose Radiation Dosimeters." Radiation Physics & Chemistry, 23, 441-444.
- Frank H. Attix and Eugene Tochilin (editors), 1969. "Radiation Dosimetry. Vol. 3. Sources, Fields, Measurements and Applications," 2nd edn., Academic Press, New York, N.Y.
- Thomas D. Boyce and Steve Boom, 1982. "Removal of Soluble Radium from Uranium Minewaters by a Selective Complexer." Preprint No. 82-23, Society of Mining Engineers of AIME, Littleton, Colorado.

Gladys White Grodstein, 1957. "X-Ray Attenuation Coefficients from 10 kev to 100 Mev." National Bureau of Standards Circular 583.

R.G. Jaeger (Editor-in-Chief), 1968. "Engineering Compendium on Radiation Shielding. Vol. 1. Shielding Fundamentals and Methods," Springer-Verlag, New York, N.Y.

R.A. Speranzini and L.P. Buckley, 1981. "Treatment of Spent Ion-Exchange Resins for Disposal." Atomic Energy Of Canada Limited, Chalk River Nuclear Laboratories, Report AECL-7411, September 1981.

APPENDIX F
COST ESTIMATE DETAILS

TABLE F-1
TAILINGS DECANT WATER TREATMENT PLANT
CAPITAL COST ESTIMATE DETAILS

Item	Description	Quantity	Unit	H.O. Material		Field Material		Total Material	Total Labour	Total \$
				Unit Cost	Total	Unit Cost	Total			
1	Building	2560	m ³			63.25	162,000	162,000	162,000	324,000
2	Decant Water Line	500	m	15.20	7,600	5.80	2,900	10,500	2,900	13,400
3	Backwash Return Line	600	m	11.83	7,100	5.00	3,000	10,100	3,000	13,100
4	Powerline and Substation	1	LS				43,000	43,000	21,600	64,600
5	Sand Filter Feed Tank (6000 mm diam. x 6000 mm)	1	LS		30,000			30,000		30,000
6	Sand Filter Feed Pumps (150 mm x 100 mm)	2	Ea	3,900	7,800			7,800		7,800
7	Motor (22.5 kw)	2	Ea	1,300	2,600			2,600		2,600
8	Sand Filters c/w Controls (2440 mm diam. x 3700 mm)	3	Ea	60,000	180,000			180,000		180,000
9	Resin Column Feed Tank (6000 mm diam. x 6000 mm)	1	LS		30,000			30,000		30,000
10	Resin Column Feed Pumps (150 mm x 100 mm)	2	Ea	3,900	7,800			7,800		7,800
11	Motors (22.5 kw)	2	Ea	1,300	2,600			2,600		2,600
12	Backwash Pumps (100 mm x 75 mm)	2	Ea	2,900	5,800			5,800		5,800

Table F-1 (cont'd)

Item	Description	Quantity	Unit	H.O. Material		Field Material		Total Material	Total Labour	Total \$
				Unit Cost	Total	Unit Cost	Total			
13	Motors (22.5 kw)	2	Ea	1,300	2,600				1,300	2,600
14	Resin Columns c/w Controls (2240 mm diam. x 3700 mm)	3	Ea	60,000	180,000				180,000	180,000
15	Resin Trap	1	LS		10,000				10,000	10,000
16	Spent Resin Tank (3000 mm diam. x 3000 mm)	1	LS		10,000				10,000	10,000
17	Spent Resin Pump (100 mm x 75 mm)	1	Ea	2,900	2,900				2,900	2,900
18	Motor (22.5 kw)	1	Ea	1,300	1,300				1,300	1,300
19	Backwash Surge Tank (4000 mm diam. x 4000 mm)	1	LS		20,000				20,000	20,000
20	Backwash Surge Pumps (100 mm x 75 mm)	2	Ea	2,900	5,800				5,800	5,800
21	Motors (22.5 kw)	2	Ea	1,300	2,600				2,600	2,600
22	Decant Area Sump Pump c/w Motor (50 mm)	1	Ea	3,500	3,500				3,500	3,500
23	Tailings Pond Barge Pumps (150 mm) c/w Floats and Building	1	LS		175,000				175,000	175,000
24	Air Compressor c/w Motor (200 m ³ /h @ 414 kPa)	1	LS		7,500				7,500	7,500
25	Hoist	1	LS		2,500				2,500	2,500

Table F-1 (cont'd)

Item	Description	Quantity	H.O. Material		Field Material		Total Material	Total Labour	Total \$
			Unit	Unit Cost	Unit Cost	Total			
	Field Material for Item 5 to 25 (10% of H.O. Material)					69,000	69,000		69,000
	Mechanical Installation (22% of H.O. Material)						151,900	151,900	
	Process Piping (20% of installed mechanical)							182,200	
	Electrical (20% of installed mechanical)							182,200	
	Instrumentation (10% of installed mechanical)							91,100	
	Total Direct Costs							1,781,800	
	Construction Indirects (8%)							142,500	
	Engineering, Procurement and Construction Management (12%)							213,800	
	Capital Spares							25,000	
	Resin Inventory (27.42 m ³ @ \$11,742/m ³)							320,000	
	Sub-total							2,483,100	
	Contingency (10%)							248,300	
	TOTAL ESTIMATED CAPITAL COSTS							2,731,400	

TABLE F-2
TAILINGS DECANT WATER TREATMENT PLANT
ANNUAL OPERATING COST ESTIMATE DETAILS

<u>1. Manpower</u>	<u>Requirement</u>	<u>Rate</u>	<u>Annual \$</u>
Operator	0.25 man/shift	\$15.75/hour	30,320
Maintenance	5 man days/month	\$16.80/hour	11,100
Supervision	0.1 man/shift	\$3,675/month	4,410
Environmental	0.25 man/day	\$3,675/month	11,025
Analytical	1.0 man/day	\$2,890/month	34,680
Sub-total			91,535
Payroll Burden (25%)			22,900
TOTAL MANPOWER COSTS			<u>114,435</u>
<u>2. Reagents and Supplies</u>			
Resin -21.8 m ³ /a @ \$11,772/m ³ (\$250 (U.S.)/cu. ft.)			256,630
Supplies (lump sum)			50,000
TOTAL REAGENTS AND SUPPLIES			<u>306,630</u>
<u>3. Power and Heating</u>			
Power 1,000,000 kwh/year @ \$0.11/kwh			110,000
Heating 40,000 L propane @ \$0.21/L			8,400
<u>4. Roads and Yards (Lump Sum)</u>			2,500
Sub-total			541,965
Contingency (5%)			27,100
TOTAL ESTIMATED ANNUAL OPERATING COSTS			<u>569,065</u>

POOR

QUALITY

ORIGINAL